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Quarterly Progress Report

Division 5

15 December 1959

Information Processing

AFCRC-TN-59-1026

Lincoln Laboratory
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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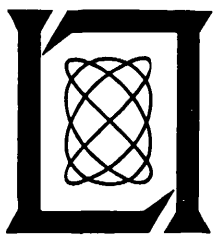
Lexington, Massachusetts



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INTRODUCTION

This Division 5 Quarterly Progress Report covers the period from 1 September through 30 November 1959.

Activity within the Division during this period in support of the AICBM program is reported in the AICBM Quarterly Progress Report. Division 5 work on Project Needles is reported in the Division 3 Quarterly Progress Report. Work on the Army Data Processing program is reported within the Division 2 Quarterly Progress Report.

The past quarter has seen a continuation of research and development within several areas. The magnetic film configuration memory has been functioning satisfactorily in the TX-2 computer and considerable effort has been expended on the growing input-output system of the computer.

Progress in magnetic films has continued, spurred on by the success of the first memory unit in the computer. Design has begun on a small test computer to incorporate a magnetic film memory and 50-megapulse transistor circuitry.

The ECCO encoder and decoder have been completed and tested. Both units are operating reliably and will be used with telephone communications lines soon.

In addition, studies are continuing in pattern recognition, man-machine relationships, coding theory, and other related fields.

W. B. Davenport, Jr.
Head, Division 5

F. C. Frick
Associate Head, Division 5

15 December 1959

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Technical Reports

TR No.				Classification Report	Classification Title
206	The ACM-52 Automatic Clutter Mapper and Preliminary Experimental Results	J.N. Harris E.J. Madle	30 July 1959	U	U
208	On the Band Structure of Transition Metals and Their Alloys	J.B. Goodenough	1 Sept. 1959	U	U
210	Studies in Partial Switching of Ferrite Cores	R.H. Tancrell R.E. McMahon	21 Sept. 1959	U	U

Journal Articles

JA No.			
964	The Detection of Statistically Defined Patterns in a Matrix of Dots	B.F. Green, Jr. A.K. Wolf B.W. White	Am. J. Psychol. 72, 503 (1959)
976	Likelihood Ratios of Gaussian Processes	T.S. Pitcher	Arkiv Mat. 4, 35 (1959)
1058	Empirical Tests of an Additive Random Number Generator	B.F. Green, Jr. J.E.K. Smith L. Klem	J. Assoc. Comp. Mach. 6, 527 (1959)
1132	On the Matrix Riccati Equation	J.J. Levin	Proc. Am. Math. Soc. 10, 519 (1959)
1264	Results Obtained from a Vowel Recognition Computer Program	J.W. Forgie C.D. Forgie	J. Acoust. Soc. Am. 31, 1480 (1959)
1290	Suggestion Concerning Magnetic Interactions in Spinels	D.G. Wickham J.B. Goodenough	Phys. Rev. 115, 1156 (1959)
1443	The TX-2 Light Pen	B.M. Gurley C.E. Woodward	Electronics 32, 85 (20 Nov. 1959)

* * * * *

UNPUBLISHED REPORTS

Journal Articles

JA No.			
1447	On the Direct Cation-Cation Interactions in Several Oxides	J.B. Goodenough	Submitted to Phys. Rev.
1456	Studies in Partial Switching of Ferrite Cores	R.H. Tancrell R.E. McMahon	Submitted to J. Appl. Phys.

Journal Articles (Continued)

JA No.			
1462	The Preparation of Stoichiometric Ferrites	D.G. Wickham E.R. Whipple E.G. Larson	Submitted to J. Inorg. Nucl. Chem.
1489	Decoding Linear Error-Correcting Codes	N. Zierler	Submitted to Trans. I.R.E., PGIT
1501	Global Asymptotic Stability for Nonlinear Systems of Differential Equations and Applications to Reactor Dynamics	J.J. Levin J.A. Nohel*	Submitted to Proc. Symp. Ord. Eqs.
1511	Length of Series and the Learning Curve	N.C. Waugh	Submitted to Am. J. Psychol.
1522	Magnetization Reversal and Asymmetry in Cobalt Vanadate (IV)	N. Menyuk K. Dwight D.G. Wickham	Submitted to Phys. Rev. Letters

Meeting Papers†

JA No.			
1458	Pattern Recognition – Human and Otherwise	F.C. Frick	IBM Research Laboratory, Yorktown Heights, 21 September 1959
1472	The Spin Wave Spectrum in Magnetic Films	R.F. Soohoo	American Physical Society, Pasadena, 28-30 December 1959
1486	Anisotropy and Inversion in Permalloy Films	D.O. Smith E.E. Huber, Jr. M.S. Cohen G.P. Weiss	1959 Conference on Magnetism and Magnetic Materials, Detroit, 16-19 November 1959
1487	Investigations into the Origin of Anisotropy in Oblique-Incidence Films	M.S. Cohen E.E. Huber, Jr. G.P. Weiss D.O. Smith	1959 Conference on Magnetism and Magnetic Materials, Detroit, 16-19 November 1959
1493	Digital Computer Techniques in the Study of the Nervous System	W.A. Clark	I.R.E. Meeting, Boston, 8 December 1959
1518	Activity in Networks of Neuron-Like Elements	B.G. Farley W.A. Clark	Fourth Annual Meeting of Biophysics Society, Philadelphia, 24-26 February 1960; International Symposium on Information Theory, London, 29 August – 3 September 1960; National Aeronautical Electronics Conference, Wright Patterson AFB, 3 May 1960
1519	On Quantifying the Electrical Activity of Nervous Systems	T.T. Sandel	Northwestern I.R.E. Section, Williamstown, 4 December 1959

* Author not at Lincoln Laboratory.

† Titles of Meeting Papers are listed here for information only. No copies are available for distribution.

DIGITAL COMPUTERS
GROUP 51

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SAVELL, R. E.
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* Leave of Absence
†Staff Associate

DIGITAL COMPUTERS
GROUP 51

I. SUMMARY

The magnetic film memory for "configuration control" has been functioning satisfactorily in the TX-2 computer. A 4096-register, completely transistorized, ferrite-core bank was added to TX-2's central memory and is being tested for a read-write cycle time of 4.4 μsec. During the quarter a considerable amount of activity was expended on the growing input-output system of the computer, as covered in some detail in the body of this report.

Progress in magnetic films continued, spurred on by the success of the first unit in the computer, by some encouraging new electroplating results, and by renewed interest in much smaller spots.

Design has begun on a small test computer to incorporate a magnetic film memory and high-speed transistor circuitry. The machine, FX-1, will test the memory, circuit and packaging techniques on a scale sufficient to prove their feasibility for future full-scale computers.

II. COMPUTER DEVELOPMENT

A. TX-2

1. Memories

The 32-word 10-bit magnetic film configuration memory has been in operation for four months. It has an excellent operational record, with only several information-loss incidents, one or two caused by power line transients and the remainder by circuit faults. A temperature problem exists in several plug-in units. The driver packages contain resistors which increase the package temperature above specified ratings. Also, a small temperature rise in the strobe units has the effect of shifting the slice level and causing information loss. A fan has been installed pending redesign of the offending units.

T. O. Herndon

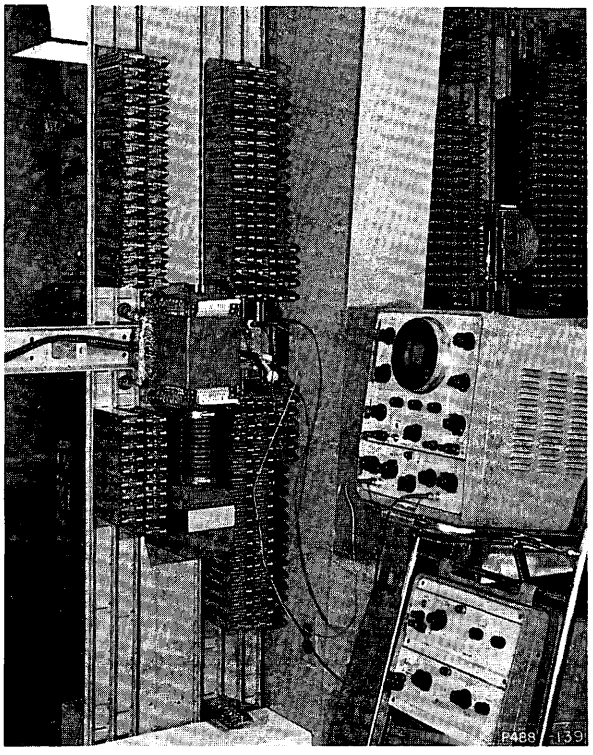

Fig. 51-1. Transistor-driven ferrite-core memory on test in TX-2.

The "T" memory, a transistor-driven, ferrite-core memory containing 4096 38-bit words has been installed in the computer and is now under test, as shown in Fig. 51-1. This memory is a random-access coincident-current unit which employs a two-coordinate "read" and three-coordinate "write." The magnetic cores (50 mils o.d. 30 mils i.d.) switch in 1.0 μsec when driven with 480 ma. The memory has a read-write cycle time of 4.8 μsec which will very likely be shortened to 4.4 μsec –

the speed at which tests are presently under way. The memory requires approximately 1000 transistors plus a few diodes.

P. E. Barck

2. Input-Output

Two new sequences were added to the TX-2 input-output system, an alarm sequence and a trapping sequence. Both are "machine state" sequences not associated with a particular input or output device. The alarm sequence raises a flag when an unusual state occurs in an input or output unit; for example, if the program falls behind the unit, or if a supply of stock (film, paper) is low. The trapping sequence raises a flag when a specified state in the central machine is reached; for example, the execution of a particular instruction, or the addressing of a register whose meta bit has been set. New sequences now under construction include a miscellaneous-inputs sequence and an interval-timer sequence. In addition, a central-machine real-time clock is being fabricated.

C. S. Lin

The high-speed Xerographic printer has been fitted with a new charactron embodying a new electron gun design by Stromberg-Carlson and a new 88-character matrix designed at Lincoln. The characters are designed to match as closely as possible those on the Lincoln Writer in order to allow the use of the same typing format and conventions on both the Lincoln Writer and the Xerographic printer. The new electron gun design gives less deflection distortion than did the one in the previous charactron and allows control of character size by the computer.

R. H. Gould

Design of the new photoelectric tape reader (PETR Mk II) was completed in October, and a prototype should be available by the first of the year. It is expected that a month of work with the machine will be sufficient to evaluate the performance of the different optical systems under consideration and to eliminate any mechanical shortcomings in the design. In brief, it is anticipated that the first machine will be "on line" by early 1960.

A. W. Case

Lincoln Writer operating experience suggested several modifications which have been incorporated into the prototype and are being included in the six units under construction. The Lincoln Writer is now being used as the direct communication link between programmer and computer. The programmer may communicate with his program in the computer's own language, using the keyboard or reader as inputs and the typewriter or punch as outputs. He may also use the Lincoln Writer "off-line" to prepare tapes.

A design that will consolidate the rather spread out input-output equipment into a more efficient arrangement has commenced. Tentative plans are being made around an L-shaped sloping-front console which will house maintenance controls at one end and operating controls at the other.

R. E. Savell

Operation of the magnetic-tape system with the computer has started. The motion control system is completely "debugged" and performs satisfactorily. Final shakedown of the information-handling portion of the system is awaiting the elimination of a stability problem in the read amplifier.

J. E. Laynor
T. C. Stockebrand

Two changes have been made in the random number generator in order to eliminate the bias in its output.* First an extra stage was added to the counter to eliminate a timing race. Second, a prf problem apparently caused by hole storage in a pulse-gating transistor was eliminated by rearranging the logic so that the transistor sees a constant pulse pattern. The second change caused the largest improvement in the operation.

L. Neumann

B. Fabrication Techniques

1. Deposited Connections and Wiring

A new approach to the interconnection of layers of etched wiring is shown in the binary-counter panel of Fig. 51-2. The layers of wiring have been separately etched, laminated to a plastic base containing encapsulated sockets, capped with an additional layer of plastic, and drilled wherever the etched wires must be connected to each other or to the sockets. Copper, chemically deposited into the drilled holes, forms deposited connections between layers of etched wiring and the sockets. Additional electrodeposited copper ensures adequate conductor thickness. Finally, the surface copper has been removed to electrically separate all the holes.

2. Bioelectric Probe

A multiple-contact probe for sensing bioelectrical signals has been fabricated for the Communications Biophysics group of R.L.E. at M.I.T.; it is shown in Fig. 51-3. At the probe tip is a square array (Fig. 51-4) of twenty-five 0.0005-inch diameter tungsten wires spaced on 0.006-inch centers. The wires protrude approximately 0.0005 inch from the probe face.

Details of construction are shown in a photograph of the assembly jig (Fig. 51-5). Each of the 25 probe wires was fastened to a terminal in the bottom of the plastic cylinder and held tight by a rubber band attached to the other end. Two sets of six spacer wires positioned at right angles to each other spaced the 25 wires in a square array at the position which was to become the probe face. The probe wires were coated with silicone mold-release fluid before encapsulation; after facing off, the final polishing was performed at an elevated temperature. The thermal coefficient of expansion of the epoxy-resin encapsulment is many times that of the tungsten wires and the mold-release fluid allows the plastic to expand relative to the probe wires during heating. After polishing, the plastic shrinks relative to the wires (during cooling), allowing them to protrude the desired amount.

E. A. Guditz

C. Advanced Circuits

1. High-Speed Diode Testing

A very effective technique for making recovery time tests on high-speed diodes is shown in Fig. 51-6. Forward bias is supplied by the battery and R_1, reverse drive comes from the mercury relay pulse generator which is part of the Lumatron oscilloscope. The various lengths of delay cable and attenuator pads are to prevent reflections or to delay them until the diode has recovered. The series impedance through which the diode is being turned off is 225 ohms. A cross section of the diode jig is shown in Fig. 51-7.

K. H. Konkle

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* Division 5 Quarterly Progress Report, Lincoln Laboratory, M.I.T. (15 September 1959).

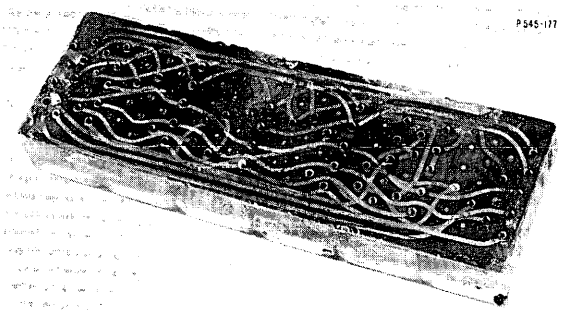

Fig. 51-2. Laminated layers of etched wiring interconnected by means of plated-through holes and deposited connections.

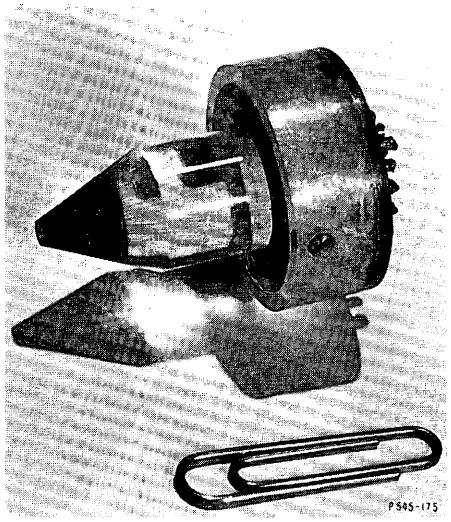

Fig. 51-3. Bioelectric probe.

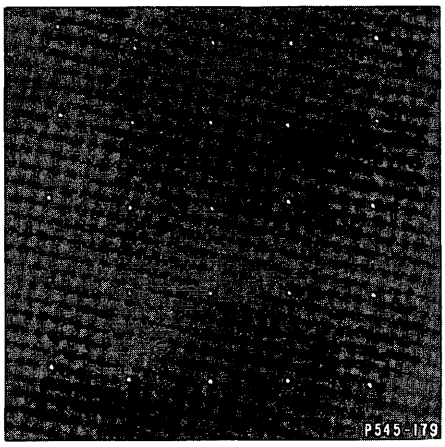

Fig. 51-4. Photomicrograph of probe tip. Tungsten wires are 0.0005-inch diameter on 0.006-inch centers, and protrude approximately 0.0005 inch.

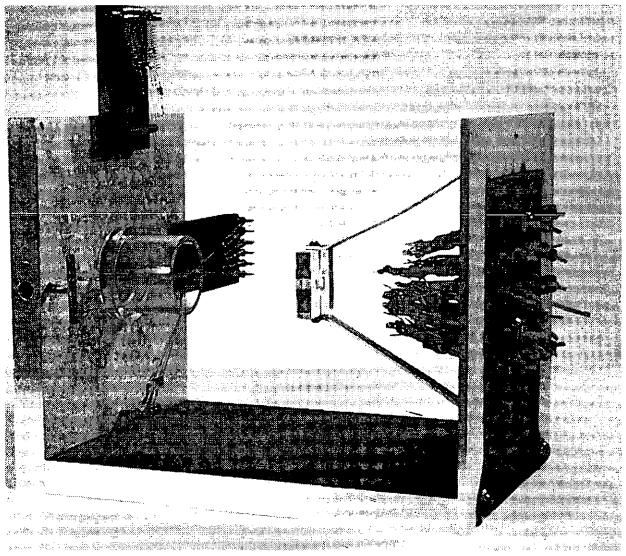

Fig. 51-5. Assembly jig used in making probe.

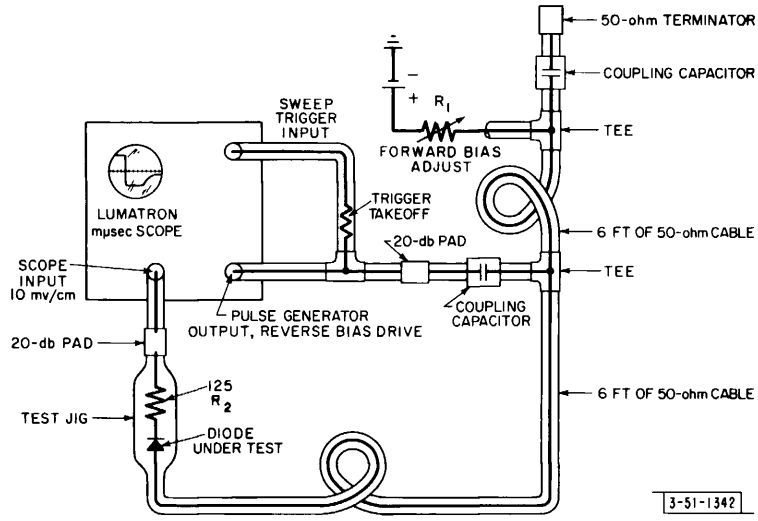

Fig. 51-6. Diode recovery tester.

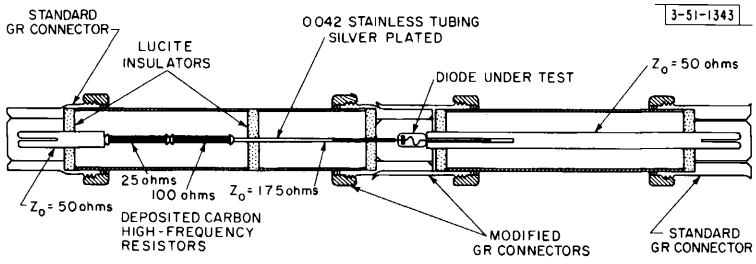

Fig. 51-7. Test jig.

2. Gated Pulse Amplifier

The gated pulse amplifier (Fig. 51-8) utilizes negative 10 mμsec pulse 1.25 volts in amplitude with a maximum prf of 25 megapulses/sec. It is controlled by a 0- or −1.5-volt level and will drive three 93-ohm cables. The circuit is a preliminary design for feasibility studies; with the advent of new transistors it will be modified accordingly.

L. Neumann

D. New Test Computer, FX-1

A new, small computer is under design to serve as the vehicle for development and evaluation of higher-speed basic techniques including magnetic films, 50-megapulse transistor and diode circuits, and multilayer deposited wiring. The computer will be no larger than necessary to provide the data and experience for designing very large computers based on these new techniques. With this in mind, the following specifications have been tentatively set:

(1) A 256-word 14-bit magnetic film memory having a read-write cycle time of approximately 0.3 μsec will be used.

(2) Logic circuitry will be an unclocked, mixed system comprising: DC level logic circuits using saturated transistors and diodes, level-gated pulse amplifiers having a nominal pulse width of 10 mμsec, lumped or distributed delay lines, and 50-megapulse static-type flip-flops.

(3) Backpanel and plug-in-unit wiring will include multilayered etched wiring with plated-through connections dip-soldered to connectors and components.

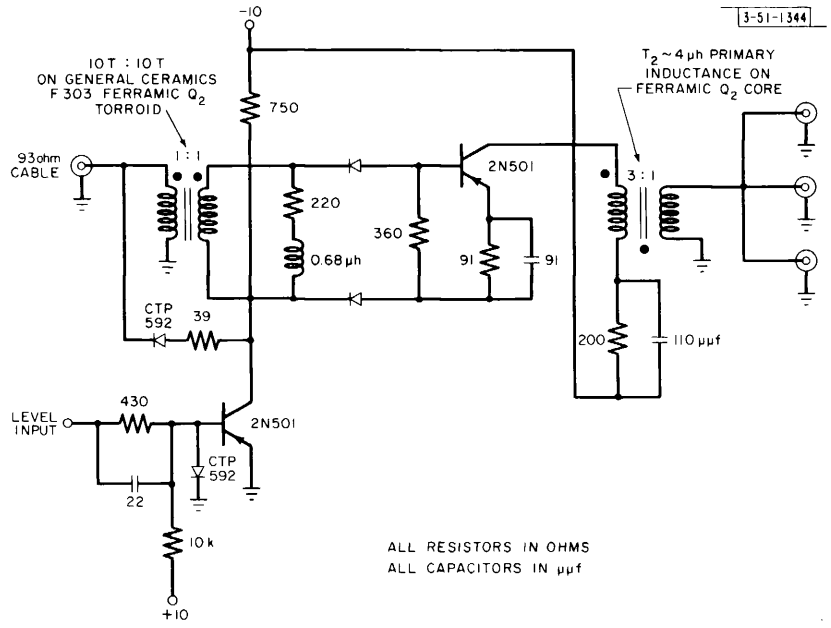

Fig. 51-8. Gated pulse amplifier.

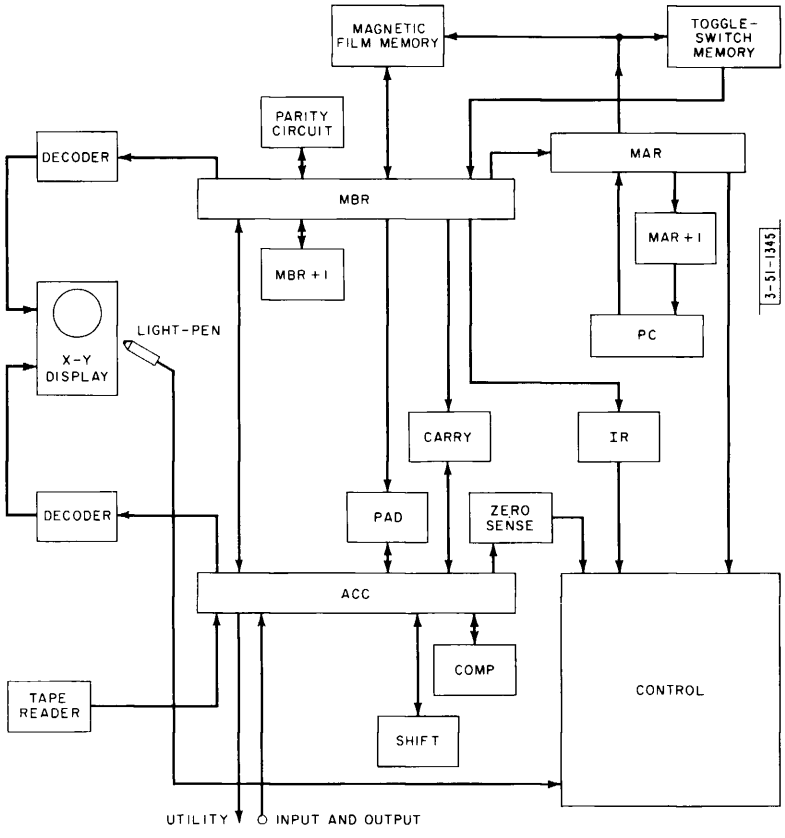

Fig. 51-9. FX-1 system schematic.

(4) A minimum number of registers will be used. However, the order code list will be relatively large in order that a large number of logical operations – i.e., shifting, counting, adding, zero detection, parity checking, and their control – can be tried out in a small system.

(5) In-out equipment will be kept to a minimum, and will consist of an X-Y point-display scope, a light-pen for use with the scope, medium-speed line-by-line paper-tape reader, a small toggle-switch memory, indicator lights, and a utility input and output channel for future applications.

The machine organization as presently conceived is shown in Fig.51-9. As can be seen, only five basic registers have been used: Memory Address Register (MAR), Program Counter (PC), Memory Buffer Register (MBR), Accumulator (ACC) and Instruction Register (IR). A 12-bit word will be used, with the first four being the order code, and the last eight addressing the memory or specifying the operate class command. An additional bit will be added for parity check of memory words. Approximately sixteen of the memory addresses will refer either to toggle-switch memory or to the film memory, depending on a mode switch. Several other mode switches will cause the computer to read tapes, run through a memory test pattern, or perform some other special function. The display scope deflection will be determined by the contents of ACC and MBR. The light-pen will be an input device which will cause the program to branch if it detects a flash on the scope face. The order code can be broken into several types: those affecting both memory and accumulator, those affecting only the memory, those affecting the program counter, those of an in-out type, and the operate class commands which do not refer to memory but which can affect the accumulator, program counter, in-out device, or the mode of the computer.

One proposed order code list is given below where: ACC = contents of Accumulator, X = address section of instruction, M_x = contents of memory register X, PC = contents of Program Counter, MAR = contents of Memory Address Register, D_v = vertical deflection of scope, D_h = horizontal deflection of scope, X_{se} = address section with sign extended.

Type	Name	Description	
M & ACC	LDA	Load ACC from M	$M_x \rightarrow ACC$
	STA	Store ACC in M	$ACC \rightarrow M_x$
	EXA	Exchange ACC & M	$M_x \rightarrow ACC$, $ACC \rightarrow M_x$
	ADD	Add M to ACC	$ACC + M_x \rightarrow ACC$
	AUG	Add ACC to M	$ACC + M_x \rightarrow M_x$
X	CRM	Cycle right M	Rot. $M_x \rightarrow M_x$
	SRM	Shift right M	$2^{-1} M_x \rightarrow M_x$
	CTM	Count in M	$M_x + 1 \rightarrow M_x$
PC	JMP	Jump	$X \rightarrow PC$
	JNA	Jump on negative A	$ACC \geqslant 0$, $PC + 1 \rightarrow PC$ $ACC < 0$, $X \rightarrow PC$
	SNM	Skip on negative M	$M_x \geqslant 0$, $PC + 1 \rightarrow PC$ $M_x < 0$, $PC + 2 \rightarrow PC$
	DEF	Defer to X	$X \rightarrow MAR$, $PC + 1 \rightarrow PC$ then repeat instruction cycle
IO	DIS	Display	$ACC \rightarrow D_v$, $M_x \rightarrow D_h$, Intensify scope
OP	ADC	Add a constant	$X_{se} + ACC \rightarrow ACC$
	OPR	Operate	X defines operate class command

The operate class commands are: clear ACC, clear and complement ACC, complement ACC, shift ACC, cycle ACC, multiply step ACC, skip on bit of ACC, make bit of ACC "zero" or "one", or complement it, clear overflow, skip on overflow, skip on light-pen, read one line of tape, read two lines of tape, skip on input indicator, strobe input channel, skip on output indicator, store TBR in MBR, store TBR in ACC, store TAC in ACC, etc.

K. H. Konkle

III. MAGNETIC FILM ENGINEERING

A. Film Characteristics and Fabrication

1. Uniformity Statistics for Evaporated Films

The uniformity of wall coercive force H_c and rotational coercive force H_k has been measured for three types of substrate preparations: (a) ultrasonically cleaned glass, (b) ultrasonically cleaned glass subjected to ion bombardment for one minute prior to Permalloy evaporation and (c) ultrasonically cleaned glass coated with a layer of SiO prior to Permalloy evaporation.

The uniformity of H_c within a plane is obtained by measuring the percentage of the spots at least partially switched for each of two settings of digit-current amplitude. If a normal distribution function is assumed, the standard deviation σ and mean value M can be determined. Data for uniformity from plane to plane is obtained with the hysteresigraph described by Strassberg.*

TABLE 51-I
MEMORY PLANE UNIFORMITY DATA

		Glass	Ion Bombardment	SiO
Plane to plane	No. of planes	7	13	4
	Mean H_k	2.8 oe	3.6 oe	4.2 oe
	$\sigma/M(H_k)$	0.065	0.081	0.19
	Mean H_c	1.4 oe	1.8 oe	1.5 oe
	$\sigma/M(H_c)$	0.28	0.27	0.24
Within a plane (average)	$\sigma/M(H_c)$	0.18	0.17	0.16

The results are tabulated in Table 51-I. These films were all made from melts of 83 per cent Ni and 17 per cent Fe at a substrate temperature of 300°C. Note that ion bombardment or SiO undercoat did not significantly improve the uniformity of H_c within a plane or from plane to plane. Also, the value of H_k and its uniformity appear to be best for the usual ultrasonically cleaned glass. However, only tentative conclusions should be drawn from the plane-to-plane data for the SiO because of the limited number of samples. Behrndt† obtained his best uniformity for a SiO undercoat, and our best measured uniformity of H_c within a single array (σ/M = 0.07) was obtained with the SiO undercoating.

T. S. Crowther

*D.D. Strassberg, Group Report 51-10, Lincoln Laboratory, M.I.T. (16 October 1959).

†K.H. Behrndt and F.S. Maddocks, J. Appl. Phys. 30, 276S (1959).

2. Measurements of Angular Distribution of the Easy Axis

The discrepancy between the two methods of measuring the angular distribution of the easy axis in magnetic films described in Group Report 51-2, and (briefly) in the Division 5 Quarterly Progress Report for 15 June 1959, has been resolved. An error in the derivation of Method 2 has been found and the corrected equation yields results that are in good agreement with Method 1.

T.S. Crowther

3. Electrodeposited Magnetic Films

A group of forty-one 8 × 8 electroplated arrays has been received from I. Wolf under Lincoln subcontract with General Electric. These were intentionally shipped untested. Looper data taken here indicate considerably greater plane-to-plane uniformity than in any comparable group of vacuum-deposited arrays. Uniformity within any single plane is not exceptional, but there are patterns in the characteristics which appear to repeat from plane to plane. This is very encouraging because it is hoped to eliminate such systematic effects.

The most pronounced type of nonuniformity within a plane is the variation in thickness of the Permalloy plate. This is the result of nonuniform current density over the surface of the film. A reduction of the plating current and an increase in the thickness of the sputtered gold substrate both appear to improve uniformity of plate thickness. However, these techniques cause deterioration of the magnetic properties of the film.

Other means of obtaining uniform current density at the cathode are being investigated both here and at General Electric. In general, these techniques are attempts to modify the potential distribution within the bath by changing the electrode configuration or introducing auxiliary electrodes.

A dark room is being constructed in the group laboratory for work on the photographic techniques necessary for masking plated films. Photographic masking will be especially useful in fabricating arrays of very small spots (both vacuum deposited and electroplated).

D. D. Strassberg

4. Reduced Spot Diameter

Experiments with spots in the 5-mil to 10-mil diameter range have been encouraging. Reasonably clear outputs have been obtained by switching single bits under pulse conditions. Single-domain storage properties can be obtained with a thickness of about 250 Å.

The potentiality of such spots in very high density (10,000 bits psi) memory applications is being evaluated.

J. I. Raffel

B. Test Instrumentation

1. Motorized Handler and Data Recorder for Pulse Testing

A new handler for pulse testing 16 × 16 arrays is shown in Fig. 51-10. As in the earlier testers, a spot at a time is indexed under the pair of crossed drive lines and sense coil. In this model, motion in one direction is provided by a motor-detent mechanism (shown on the left) and manually in the other direction. A 3-axis micromanipulator, on the right, is used for initial fine-position control. Position accuracy over an array and from array to array is adequate with just the initial adjustments. The complete system includes current drivers, transistor logic for programming the current pulses, oscilloscopes for pulse current and signal

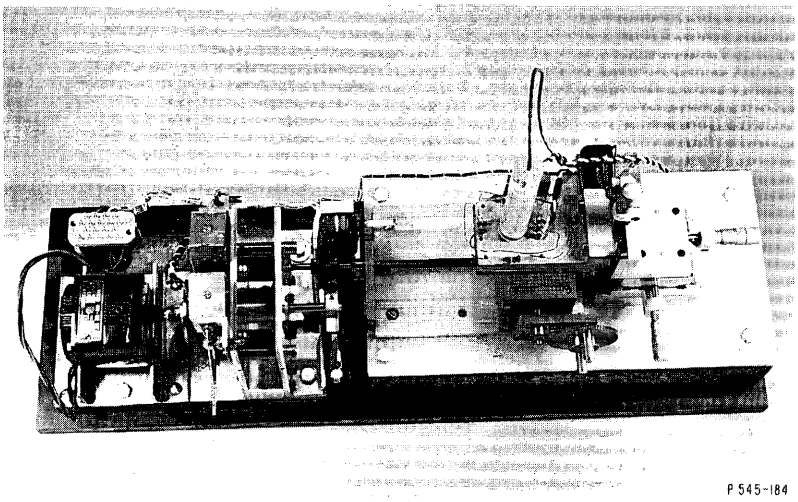

Fig. 51-10. Motorized handler and data recorder for pulse testing magnetic film spots.

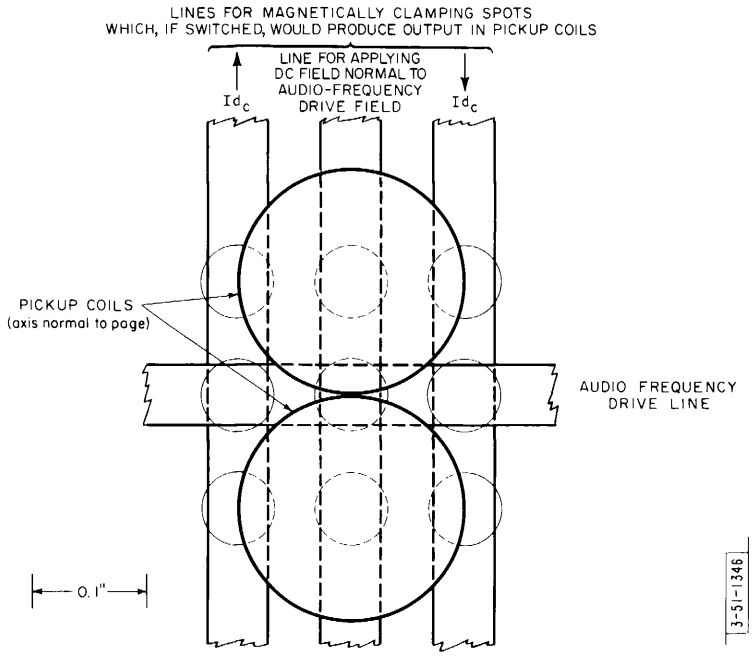

Fig. 51-11. Sketch of drive lines and pickup coils used in looper for single spots of an array. (View is from top, looking down through pickup coils and drive lines at array. The center spot is under test.)

measurement, motor-detent control logic, and a typewriter for data recording. The motor-detent mechanism is under typewriter control. When data are entered, the handler indexes one position; upon return of the typewriter carriage the handler returns to the beginning of the row and is indexed by the operator to the next column. Four counters are tied to the outputs of the four typewriter keys to enable automatic tabulation of statistics for uniformity studies within an array.

It should be possible to make a single test run on a 16 × 16 array in from 5 to 10 minutes, and provide simultaneously a concise standard record of test results. This will greatly facilitate production testing.

A. H. Anderson
D. D. Strassberg

2. Audio-Frequency Hysteresigraph

A device for looping single spots within a memory array is being tested with very encouraging results. It should prove to be a valuable adjunct to the pulse tester in determining the nature of spot-to-spot variations in film characteristics.

The instrument utilizes a manipulator identical to those used in two Lincoln pulse testers and the electronic equipment used with one of the large-sample loopers. Figure 51-11 shows the drive and pickup coil configurations. The audio-frequency drive field is supplied by a single flat conductor. Current in a pair of flat conductors provides a DC clamping field to prevent the spots adjacent to the one under test from being switched. The two series pickup coils are 0.2 inch diameter × 0.1 inch long and are mounted with their axes normal to the film.

D. D. Strassberg

C. Memory for Test Computer

The magnetic film memory for the new experimental test computer will contain 256 fourteen-bit words. Ten-to-the-inch spot density will probably be retained but serious consideration is being given to a number of changes from the techniques used in the configuration memory in TX-2. These are listed below along with some brief comments.

(1) A diode matrix to replace the diode-terminated core switch is almost certain, based on the results obtained with the 128-position experimental model.

(2) The use of plated rather than evaporated films is a better-than-even possibility. The Lincoln facility is coming into full operation and with the help of the General Electric subcontract we should be able to produce the quantity needed (roughly sixteen arrays of 16 × 16 spots) without any difficulty.

(3) The use of separately supported etched conductors to replace cemented magnet wire is quite probable. We have obtained from Sanders Associates, at negligible cost, a large quantity of high-quality lines (made from Lincoln negatives).

(4) A nondestructive readout and write-buffering scheme is a possibility. A thorough evaluation of nondestructive readout and its effect on film specifications, sensing and driver design is being made. This, in combination with a small write-buffer storage, could speed up memory operation to an effective 0.1-μsec cycle time.

(5) Use of redundancy to increase yields will depend on the uniformity situation at the time of fabrication.

J. I. Raffel

D. Circuits

1. Sensing System Design

A film-sensing system has been designed which uses a low impedance sense line (approximately 20 ohms) for maximum power transfer. It employs strip line which is 60 mils wide (one spot width) and has a spacing of 3 mils corresponding to the thickness of the thinnest glass substrate. In film switching experiments a matching transformer between the sense line and the transistor amplifier input (impedance approximately 2000 ohms) raises the voltage gain of the system by a factor of four over the unmatched case.

H. Blatt

2. Memory Driving Elements

Design of driving circuitry for the 256-word 14-bit memory is in progress, based essentially on the TX-2 configuration memory drivers. A more compact layout is contemplated, with faster decoding logic. Diode selection of the word lines is to be used, and minor circuit changes are involved to accommodate this system. It would appear that the basic rise time of these drivers, driving resistive loads, is 12 to 15 mμsec at a 350-ma current level.

The drive lines tested are two-turn printed lines on 0.002-inch Mylar backing. The wire is approximately 0.025 inch wide of 0.002 inch thickness. Characteristic impedance is on the order of 90 ohms in the configuration anticipated for the memory, but it may be reduced to 50 ohms by means of a suitably placed ground plane. Current rise times of 4 mμsec have been observed with mercury-relay drive, and the input voltage waveform shows little distortion.

T. O. Herndon

E. Fixed Storage Using Films

A 2-coordinate selection system has been developed which produces smaller half-select signals than the systems considered previously. The film orientation and drive fields as well as the magnetization of the film for half-select and full-select conditions are shown in Fig. 51-12. The storage sense line detects changing flux in the transverse direction and has no coupling to H_1. The selected film is first pulsed with H_2, causing rotation of flux in half-selected films

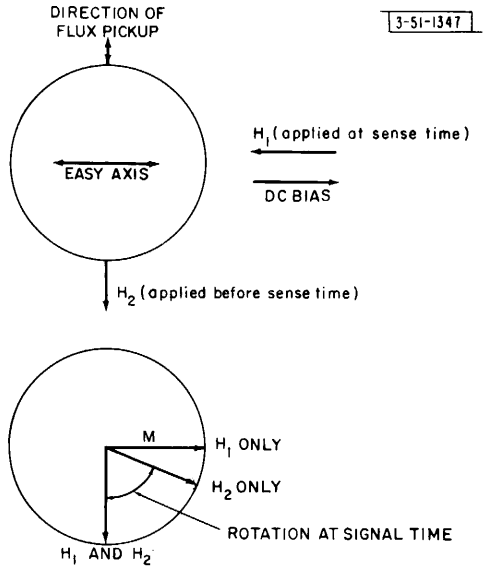

Fig. 51-12. Film orientation and magnetization states.

prior to signal time. There is no rotation in the films half-selected by H_1 (except that caused by stray fields and skew of the easy axis). Application of H_1 to the selected film cancels the longitudinal DC bias and allows the magnetization to rotate toward the direction of H_2. The optimum H_2 is equal to H_k since this produces rotation to 90°. The DC bias field and H_1 should be at least as large as H_k. Films that are multidomain at zero applied field may be used if their saturation demagnetizing field is less than H_k. Films of approximately 2500 Å are the thickest which satisfy this requirement.

A 256-word storage sense line has been tested. With 2500 Å films, "one" signals of about 0.5 mv are read out. "One-to-zero" signal ratios will be determined after a new drive-line array is constructed.

A. H. Anderson

DATA PROCESSING
GROUP 52

BIVANS, E. W., *Leader*
DINNEEN, G. P., *Assistant Leader*
WOOD, R. V., *Assistant Leader*

BINSACK, J. H.*
CHATTERTON, E. J.
DUMANIAN, J. A.
ESHLEMAN, D. B.
HARRIS, J. N.
HOROWITZ, R. M.
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LEBOW, I. L.
LONG, W. H.
LYON, E. F., III
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NAGY, F., Jr.
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DATA PROCESSING
GROUP 52

I. MAGNETIC SWITCHING MODEL

Some further investigation of the magnetic switching model TR-210 has been started. The model is being used in interpreting the work of others such as Crane of Stanford and Katz of General Electric and indicates that much of the present work in this area is closely related. In addition, there are many new questions that the model suggests which appear worthy of continued work.

The high-frequency sine wave drive used for nondestructive readout and other proposed applications is also being used to show, in a crude manner, the domain wall status throughout the material during switching. It appears that this approach may be refined to aid in the study of the walls during switching. In addition, preliminary work using the AC drive to show the switching mechanism indicates that there is little difference in the low, medium and high drive regions (corresponding to the three breaks associated with the $1/\tau$ vs H). This is of interest since it would indicate that the switching process over these three regions is predominately wall motion.

II. PERMALLOY TAPE

Work has started on the $\frac{1}{8}$-mil Permalloy tape with the hope of obtaining a useful memory element that is fast and easily fabricated by means of printed circuit techniques.

The tape elements being fabricated are circular, flat, toroidal elements cut from large flat tape. It has been found that the switching is associated only with the material directly under the drive windings and does not encompass the complete toroid. The preferred direction of magnetic orientation is responsible for this incomplete switching and some minor processing is being done to provide complete switching.

However, small rectangular tape elements that are open-ended have been used and give excellent outputs in the 50- to 100-mv range with switching times of less than 0.1 μsec. The element is arranged with a 90° bend to achieve minimum coupling between the sense and drive wires.

The tape element also offers an additional means of investigating the switching process since the fabrication of elements with added sense holes for observing switching in different portions of the element and other geometrical changes is easily done.

III. CG 24

Work has been started to determine the limiting factors in operating the memories above 72°F (at the input duct). The lower temperature limit is not known but is less than 60°F. The sense amplifiers have been checked for temperature dependence and temperature compensation is easily put in. However, it does not appear to be worthwhile at this point, since two sense amplifiers were put on extention cables and operated in an oven up to +60°C, from a low of +22°C. No errors occurred in the program during this heating cycle. It is not convenient to lower the temperature below +22°C, hence a lower limit was not found. Operation above +60°C may damage the units and it was felt that the temperature of the sense amplifiers are well above what is required.

The temperature limits of the core stack will be determined shortly.

R. E. McMahon

IV. MAGNETICS RESEARCH

The final draft of a paper describing the work in partial switching of ferrite cores has been completed. The report has been published as Lincoln Laboratory Technical Report No. 210.

Test equipment has been assembled for an experimental investigation of the response of the cores to drive currents less than 0.1 μsec in width. With previously available equipment, various degrees of partial switching in cores were achieved with current wider than 0.1 μsec. In the very narrow pulse range the reversible component of magnetization becomes very important and in the limit all flux change is reversible. For testing purposes a sampling scope with a response of 0.4 mμsec has been received and a mercury current-pulse-generator is now in operation.

Closely allied to these techniques is the use of high-frequency AC drive currents (approximately 10 Mcps) to interrogate the state of a core. Initial tests show that the amplitude of the core output is linearly related to the amplitude of the drive current and that the signal-to-noise ratio is independent of the amplitude of the AC. Work has been done on a memory scheme in which the basic memory element consists of two ferrite cores wired such that the output from an element in a "1" state to an AC interrogate current is in phase with the drive current and is 180° out of phase for a current in the "0" state. The phase of the output is independent of the amplitude of the drive current and the technique is nondestructive of the state of the memory element. A further advantage of this scheme is that very little power is required to change the state of the element since only a small percentage of the total flux of the core need be switched irreversibly. The exact amount of flux switched is not critical because this technique can detect very small differences in the magnetic states of the two cores making up the element.

R. H. Tancrell

V. HIGH-SPEED MEMORY

A. Present Status

The assembly of the high-speed-memory system is partially complete. The final core stack (83,200 cores) was assembled and mounted on slides in the memory, the full complement of 1040 word drivers are operating in the modulo-four shift-clock address mode, all of the logic and timing circuitry is installed and operating, the logic and power distribution wiring is complete, and all power supplies have been installed and are operating at current levels very near the average demands of the final system.

B. Remaining Work

The remaining details of the system consist of optimally matching the impedance of the sense windings to the inputs of the sense amplifiers, installing the remainder of the exciter drivers, and running programs through the machine to insure that false information is not generated through coupling between the exciter winding and the sense winding on the same and on adjacent modules.

C. Exciter Driver

When the complete stack of ten core arrays was assembled, its impedance was measured and found to consist of approximately 10-ohm resistance and 10-μh inductance in series. With the 6-volt swing available from the original exciter driver, the rise time of the current was found to be unsuitable for reliable operation of the memory. This stems from the fact that the

necessary current level required for the write pedestal cannot be established before the peak value of the write impulse current occurs when the memory is attempting to preserve "old" information.

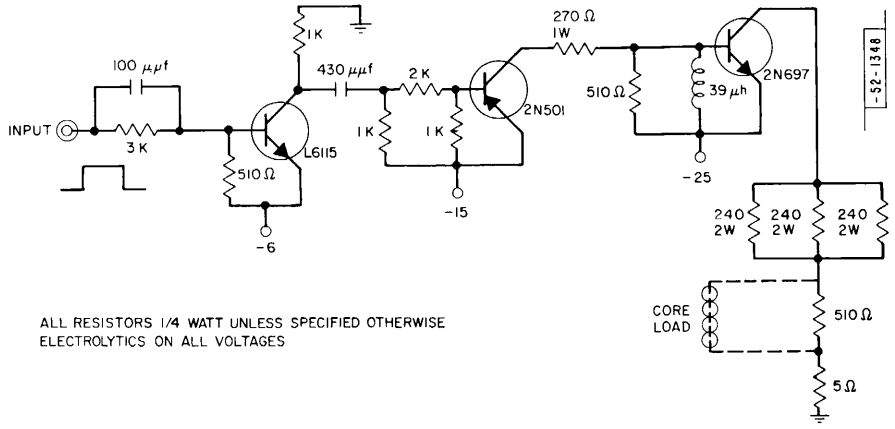


Fig. 52-1. Exciter driver.

Since the time of the first exciter driver design, several new transistors have become available which are capable of operation at the speeds, and current and voltage levels required in the exciter driver. As a result of this it was possible to design a driver of considerable simplicity to replace the first exciter driver. This circuit is shown in Fig. 52-1. The principal difference between the two circuits is in the output stage. The output transistor of the new driver is a 2N697 (Fairchild n-p-n mesa) which acts on the core load through a series resistance of approximately 100 ohms. This allows the current level to be sufficiently established in 0.1 μsec from the time the driver receives an input pulse. The previous driver (which uses five Philco 2N501 transistors to close a 6-volt switch in the output stage) is still used as a clock buffer to distribute fast high-current pulses throughout the machine at the low impedance level originally intended.

D. Sense Amplifier

The sense amplifier gives an output for inputs above a certain level, which is set by the input network in the first stage. Since the signal-to-noise ratio of the cores is at least 3:1, a fixed level may be chosen for all sense amplifiers which is above the largest "zero" output expected from any core. The impulse switching mode used in the memory, coupled with the linear selection drive, insures that no noise "accumulates" in the core as a result of its previous history since the overdrive read pulse resets all of the previously disturbed flux each time the core is addressed. Therefore, once the clip level is established for the "worst zero" condition, the only noise that can generate a false "one" is coupling from the exciter winding in the same or in adjacent channels. Because of the nature of the memory timing and the rapid recovery of the sense amplifier, only the coupling that occurs during the leading edge of the exciter waveform can generate undesirable signals in the sense winding, since it comes quite close to the time that the cores are switched in the read part of the cycle. This coupling may be entirely eliminated by the strobe gate in the Memory Transfer Logic; however, for low core outputs and those that are slightly delayed due to address timing, the strobe may also cause the system to lose "one" outputs. Much of the remaining work of the memory is concerned with various aspects

of this situation. A total of eight bit channels is operating with a relatively small number of errors. Each channel can be operated without errors through individual adjustment of sense and exciter winding terminations and sense amplifier clip levels. However, efforts will continue until standard values of clip level and termination may be employed on all channels. This principle has been firmly adhered to in all details of the memory system.

E. Packaging

Now that the major portion of the memory is installed and operating it is evident that the system of ground distribution between circuits has been a prime factor in eliminating "cross-talk" problems. Each printed circuit card has a solid ground strip printed along the outer border. Each subrack slot has a strip of cadmium-plated spring steel supported by cadmium-plated screws which are threaded into the body of the subrack. When the circuit cord is inserted into the slot, the spring arches against the surface of the ground strip and makes a solid contact. This makes the body of the subrack a ground plane with each cord having an intimate connection to this plane at regular intervals. Furthermore, the pressure of the springs against the boards holds them firmly in place and guarantees protection against poor ground contacts caused by vibrations or constant handling of the boards.

After two months of handling, a number of drive lines in the core stack have developed open circuits at the plug terminations. This is most likely due to some cold solder joints made during assembly. A systematic unit-by-unit examination and repair has been initiated to restore all available core windings to use. With the redesign of the exciter driver a new power supply voltage was required and purchased.

F. Small Memory

The small memory which has been used as a test model for evaluating improvements in the large system has been restored to correspond exactly to the present large memory system. It now has a capacity of 40 words of 15-bit length. However, because of the curtailed length of the sense and exciter windings, it is able to operate at a sequential address rate in excess of that of the large system.

Several techniques have been discussed by other laboratories for random address driving systems. Two of these that appear promising are the load sharing matrix (IBM) and the use of a single transistor to recharge the condensers of a large number of p-n-p-n driver circuits to enable them to operate at a high repetition rate (LITTON). Also, new cores and new transistors which are becoming available indicate that the present small memory can be converted to a random-access memory, through an efficient combination of such techniques, with relatively little effort. Plans for such a conversion are being formulated.

V. J. Sferrino

VI. DIGITAL DATA TRANSMISSION

The ECCO (error checking and correcting coder) encoder and decoder have been completed and debugged. Both units will operate reliably with voltage margins of plus or minus 30 per cent.

An error distribution recorder has been designed and is being constructed. The block diagram is shown in Fig. 52-2.

To detect errors originating in the telephone line, the 128-bit word from the encoder output is delayed by a shift register and compared with the word at the output of the telephone line. A circle-sum circuit feeds a "one" into the error counter whenever equivalent bits of the two words

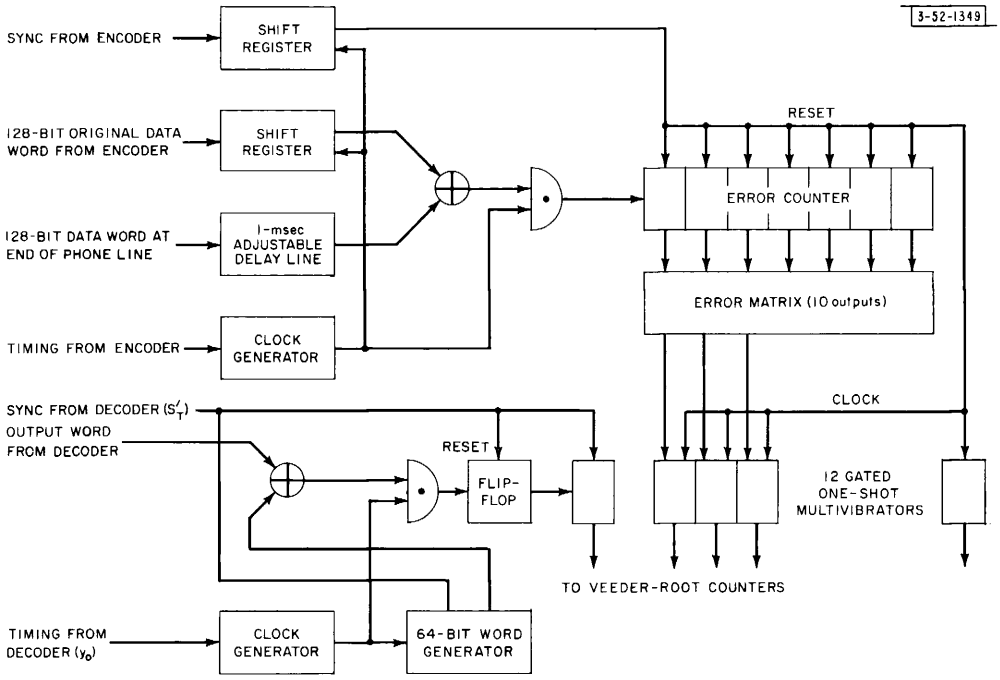


Fig. 52-2. Error distribution recorder (simplified block diagram; slicers and buffer inverters omitted).

do not agree. At the end of each word, the number of errors which have occurred in that word are represented by the state of the flip-flops in the error counter. A matrix selects a particular output line, depending upon the number of errors in the word.

Each matrix output gates a one-shot multivibrator, which drives a Veeder-Root counter. The group of counters provides a record of the distribution of errors over a period of time. For example, one of the counters registers the number of words that contain between 8 and 15 errors. The last counter is operated by the sync pulse and counts the total number of words in the test period, which may be as long as 24 hours.

The decoded 64-bit word is also checked for error. A 64-bit word generator is set to the same word as the original input to the encoder. This reference word is compared with the decoded word. A Veeder-Root counter counts the number of words in which there are one or more errors.

If the system is operating correctly, any coded word with no more than seven errors will be decoded to the original word. The count of decoded words in error would be no greater than the count of coded words with more than seven errors., If this condition is not fulfilled, it is evidence that the ECCO system is not applying the Reed-Muller code correctly, or that the test circuits are faulty.

If an error were to occur in the sync or timing channel, an error-free data word would be decoded incorrectly. This would not be a true test of the code. To avoid this complication, the sync and timing are protected. Timing is connected directly from the encoder to the decoder. Sync is delayed by a shift register to match the delay of the telephone-line loop. For fine adjustment of the delay, the data from the telephone line passes through an adjustable delay line on its way to the decoder.

D. B. Eshleman

VII. COMPUTING CIRCUITS

A number of high-speed computing circuits have been developed which depend on the impulse response of a Bessel filter. Examples of this impulse response are shown in Fig. 52-3. By slight variations of the same basic ladder network we can get either an output pulse of Gaussian shape which is useful for direct coupled logic, or a dipulse which is the optimum pulse shape for AC coupled logic.

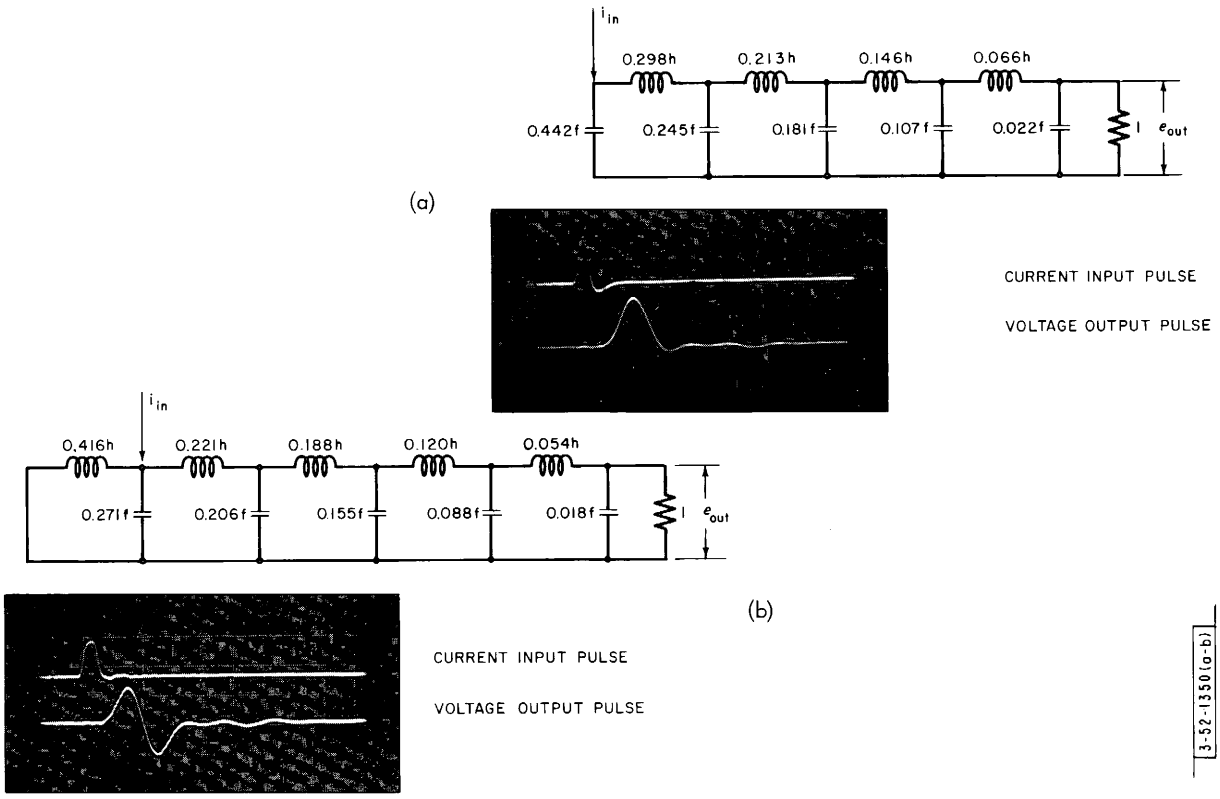


Fig. 52-3. Impulse response of a Bessel filter (normalized values): (a) current input – impulse output and (b) current input – dipulse output.

Figure 52-4 shows one circuit employing impulse response and direct coupling. The 20-Mcps sine wave input "clock" turns on transistor Q_5 only on the negative peak of each cycle. Thus a narrow (15 nanosecond)* current pulse appears at the common emitter node of Q_3 and Q_4. This pulse is steered to one or the other collector, depending on whether b or b' is lower. The current pulse excites one of the two filter circuits and impresses on the base of Q_1 or Q_2 a delayed and broadened impulse. The n-p-n transistors clip and amplify this pulse and restore the signal to ground level. If the delay is such that the center of the output pulse is coincident with the next clock pulse, then this output can control the input base (b) of one of these circuits. The other base b would be grounded.

These circuits are used in dynamic logic combinations similar to the SEAC-type logic. However, the filter response pulses are so broad that they completely overlap and the clipped outputs look like ordinary E-J flip-flop outputs. Figure 52-5 shows the result of connecting five

* Millimicrosecond.

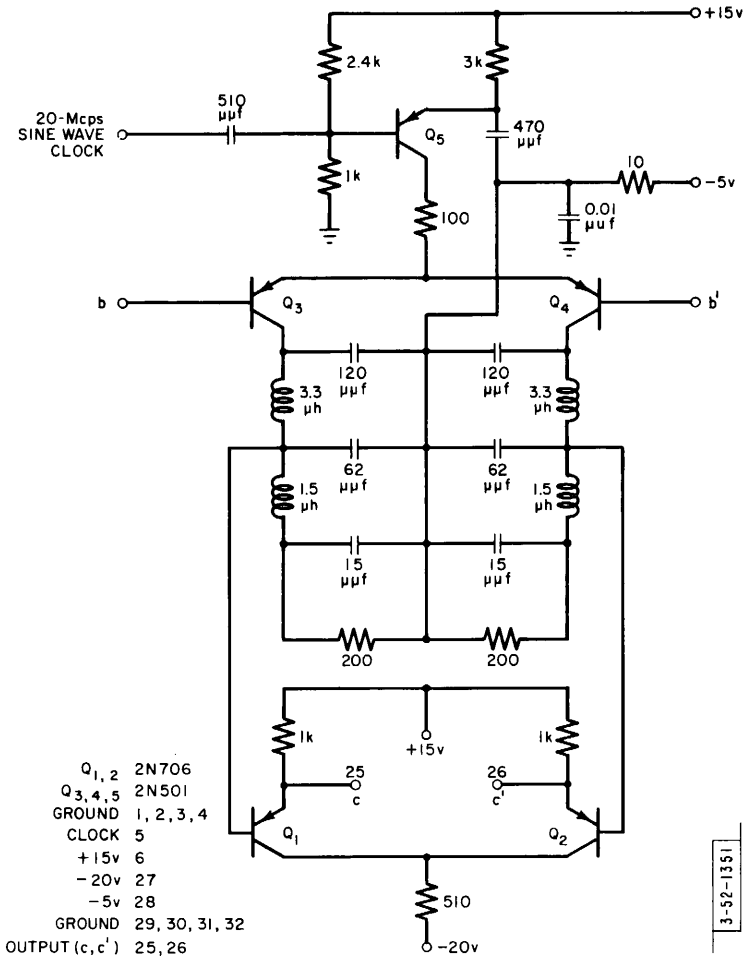
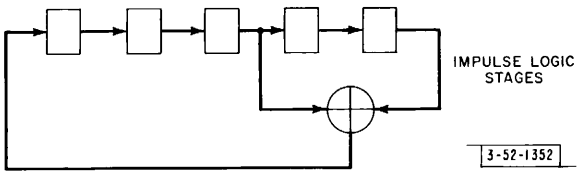
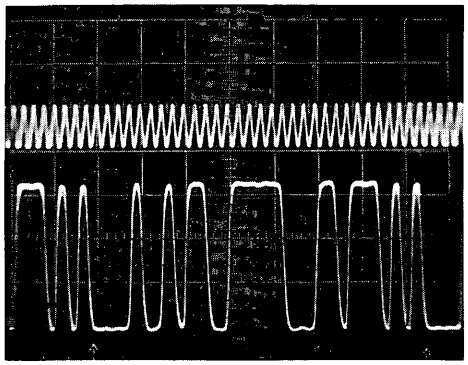


Fig. 52-4. Impulse logic (Mk IV).



Pattern 0001001011001111100011011101 01



20-Mcps clock

Bit sequence

Fig. 52-5. Linear sequence generator.

of these circuits in a shift register with circle sum feedback from the third and fifth stages. The result is a maximal length linear sequence generator which produces the 31-bit pattern shown.

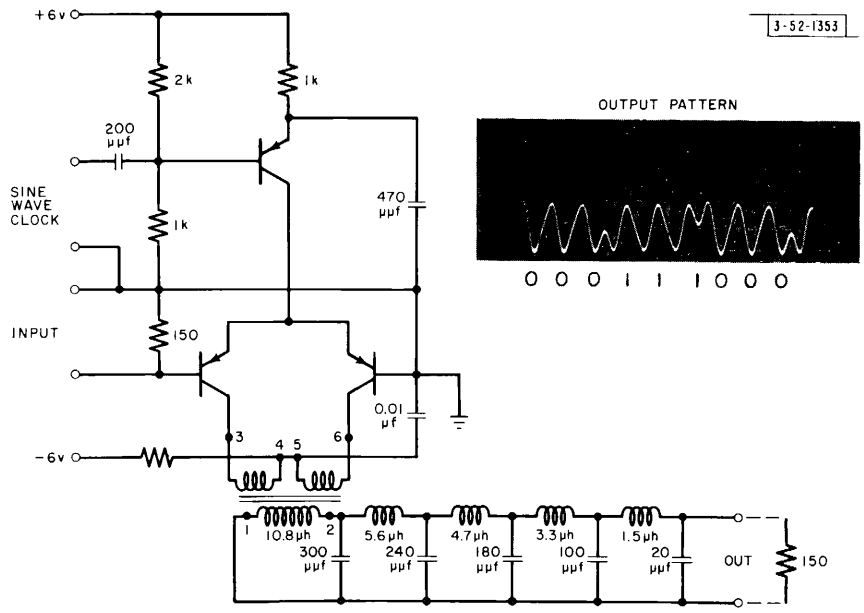


Fig. 52-6. Dipulse logic (5-Mcps data rate).

Figure 52-6 shows a dipulse logic circuit together with the pattern that results when three of these stages are connected in a simple shift register with complemented feedback. The three transistors operate as in Fig. 52-4 but a push-pull transformer couples a positive-on-negative pulse of current into the filter, depending on which transistor is turned on. The transformer secondary constitutes the shunting inductor across the filter input, which causes the filter to generate a dipulse instead of an impulse. The output dipulse will be in either of two opposite phases representing bits one and zero.

K. E. Perry

VIII. COMPUTER READOUT – COMPUTER DEVELOPMENT

The logic for the calliscope has been breadboarded, tested and found satisfactory. Both the camera and viewing cathode-ray tubes have been checked and found to more than equal the advertised resolution capabilities. Some objectionable defocusing is evident in the outer periphery of the 17-inch tube display. Further testing is in progress to determine whether a dynamic focus system should be employed. Since the deflection system is digital, the correction focus currents would have to be determined from the condition of the X- and Y-registers. The focus compensating coil would have to have an inductance at least as low as the deflection yoke.

The console should be delivered from the machine shop about the middle of January 1960.

K. E. Perry
E. J. Aho

IX. HIGH-SPEED TAPE READER

The tape reader was built to evaluate the capabilities of commercially available photoelectric devices designed for this application. In addition, the reader is to be used as a test device to provide suitable input information to the calliscope discussed in previous quarterly progress

reports. In the latter application, the reader functions as a limited capacity memory capable of sequentially furnishing the calliscope with a pair of octal numbers corresponding to the code used in the Flexowriter to represent the various alpha-numeric symbols.

The tape reader consists of a 10-inch-diameter drum, two photoelectric read heads, a variable speed DC motor and controller and a small subrack containing the necessary auxiliary electronics. The drum was assembled using two lucite rims concentrically mounted on each side of a steel base disk. Provisions for mounting and securing a perforated tape on each rim were provided. Two light sources are located approximately two inches from the rim directly in line with the drum axis and the read head center line. The optical path extends from the light bulb, through the lucite and the perforated tape to the photodiode assembly in the read head. The maximum usable length of tape per track is approximately 30 inches, providing storage of 300 octal words as punched by a Flexowriter. The drum has a maximum speed of about 3300 rpm, and therefore is capable of transmitting 16,000 words per second. The reader has been built and several heads have been assembled and tested. Thus far, preliminary tests indicate the Texas Instrument type 1N2175 n-p-n diffused silicon photo-duo-diode to be superior to the Western Electric type 1N85 p-n-grown junction phototransistor with respect to speed of operation, sensitivity and stability. To date, no tests have been conducted using the reader as an input for the calliscope.

H. Reinecke

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GROUP 53

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COMPUTER COMPONENTS
GROUP 53

I. SUMMARY

A. Magnetic Materials

In order to determine the relationship between chemistry and the intrinsic electrical and magnetic properties of materials containing transition elements, it is necessary to understand the role of the 3d electrons in chemical bonding. Previous work has concentrated on the cation-anion-cation interactions in primarily ionic materials. Theoretical consideration has been given to the transition metals and their alloys, and this work has lead to the current series of experiments on interstitial alloys. Closely associated with this work are the magnetic-form-factor measurements that are made with a polarized neutron source. Neutron-diffraction facilities are currently being designed. Theoretical and experimental work on an intermediate class of materials, those that exhibit semiconducting $\rightleftarrows$ metallic transitions, are also under way in an attempt to build a unified set of concepts that will describe the interactions of both ionic and metallic substances. Finally, the consequences of these interactions on the type of magnetic order to be anticipated in cubic spinels is also being studied.

B. Magnetic Films

Considerable progress has been made this quarter in understanding the origins of magnetic anisotropy in magnetic films. Various hypotheses have been definitely proven invalid, and there is now strong evidence for the existence of anisotropic structure faults that are sensitive to the angle of incidence of the incident depositing beam. However, these faults have not been directly observed. Considerable work remains to determine the nature of these faults and to learn how to control them. Studies of other film properties that may be useful for other applications have also been initiated. Finally, a theoretical study of the noncoherent flux-reversal process has given some insight into the mechanisms that control it.

C. Semiconducting Components

This quarter the improved cryosar elements have been investigated for possible use in high-speed computers. There is considerable similarity between possible cryosar circuits and tunnel-diode circuits, so the two components are being evaluated in parallel. In the meantime interest in the development of VHF transistors retains top priority; the transistor will undoubtedly be the active element in the 50-megapulse computer that is currently under consideration. Continued life tests on the SBT's in use in the TX-0 computer continue to give optimistic results about the reliability and life of these components.

II. MAGNETIC MATERIALS

A. Inorganic Chemistry and Crystallography

1. Vanadite Spinels

An investigation of the electrical and magnetic properties of several spinels containing vanadium, V^{3+} or V^{4+}, has been pursued through the last quarterly period. A summary of the

TABLE 53-I
ELECTRICAL AND MAGNETIC PROPERTIES OF SEVERAL SPINELS CONTAINING VANADIUM

Compound	Cubic a_o	T_c (°K)	n_B (4°K)	Maximum n_B	q* (temperature range, °C)
MnV_2O_4	8.520	~56°	$1.7\mu_B$	–	0.28 (–60 to 200)
FeV_2O_4	8.452	110 ± 1°	–	–	0 (0 to 176)
ZnV_2O_4	8.406	–	–	–	0.13 (0 to 165)
Mn_2VO_4	8.579	–	0.7 to 0.8	–	–
Fe_2VO_4	8.422	447 ± 1°	0.53	–	–
Co_2VO_4	8.385	158 ± 1°	0.1 to 0.2	0.27 (139°)	–

* q in the expression for the DC resistivity, $\rho = \rho^\circ \exp[q/kt]$.

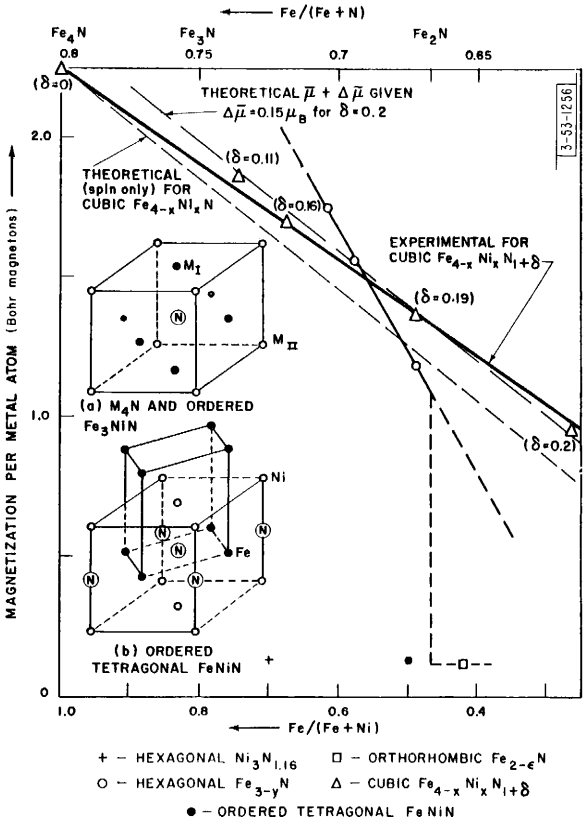

Fig. 53-1. Magnetic data and structures for several iron and nickel nitrides.

measurements so far completed is given in Table 53-I. A description of the properties of Co_2VO_4 which has been most thoroughly examined, is given in Sec. II-B-1.

D. G. Wickham K. Dwight, Jr.
N. Menyuk R. J. Arnott

2. Transition-Metal Nitrides

An interpretation of the magnetic and crystallographic properties of the system $Fe_{4-x}Ni_xN$ has been accomplished with the aid of the band-structure model for f.c.c. transition metals which has been developed previously.[1] The structures and magnetic data are presented in Fig. 53-1. The M_I atoms have e_g electrons spin-paired by the three outer p electrons of the interstitial N atom. Therefore, if the e_g orbitals that are directed toward the interstice are full, the N atom is not stable in the interstice. The outer-electron configuration for f.c.c. Fe and Ni is $Fe(e_g^{2}t_{2g}^{6-\xi}s^{\xi})$, $Ni(e_g^{4-\eta}t_{2g}^{6-\zeta}s^{\eta+\zeta})$ where $\xi \approx 1$, $(\eta + \zeta) \approx 0.6$ in pure Ni, but ~ 1 in M_4N. It follows that $\mu(Fe_{II}) \approx 3\mu_B$, $\mu(Fe_I) \approx 2\mu_B$, $\mu(Ni_{II}) \approx 1\mu_B$, $\mu(Ni_I) \approx 0\mu_B$. This leads to the theoretical curve in Fig. 53-1. Further, Ni_4N does not form by diffusion of N in from the surface since adjacent octahedra of an N-occupied octahedral interstice of a f.c.c. Ni lattice have filled Ni e_g orbitals directed into them thus inhibiting their use for N diffusion. Finally, the ordered Fe_3NiN and FeNiN phases follow from the model. These ideas were presented in a paper given at the Conference on Magnetism and Magnetic Materials, Detroit, 16-19 November 1959.

J. B. Goodenough
A. Wold
R. J. Arnott

B. Magnetic Measurements

1. Cobalt Vanadite

A study has been made of the magnetic properties of a powdered sample of cobalt vanadite, which is a cubic spinel. Paramagnetic data taken between 200°K and 450°K indicate that it forms the inverse spinel $Co^{2+}[Co^{2+}V^{4+}]O_4$. This material has a ferrimagnetic Curie temperature $T_c = 158°K$. On further decreasing the temperature, the spontaneous moment rises to a maximum at T = 139°K, then decreases to a zero net moment at the compensation temperature $\Theta = 70°K$. Below this temperature, the material exhibits a reverse thermoremanent magnetization (the other sublattice has the dominant magnetization).

The dependence of magnetization upon fields applied in the same direction as the applied field during cooling was investigated at 4.2°K. The resultant hysteresis curve shows a large asymmetry along the magnetization axis. The sample was then rotated approximately 90°, and a symmetrical loop was obtained which was otherwise similar to the first curve. Furthermore, on returning the sample to its original position relative to the field, the original asymmetry is restored. Thus 11,000 oersteds at 4.2°K is unable to destroy the memory of the field direction during cooling.

This asymmetry is in marked contrast to that observed in materials displaying exchange anisotropy,[2] in which the asymmetry is along the field axis. Reports of materials exhibiting asymmetry along the magnetization axis have been limited to a small effect in antiferromagnetic UMn_2 (Ref. 3) and a two-phase magnetic system containing αFe_2O_3 and $LaFeO_3$ (Ref. 4). In the latter case the hysteresis loop was explained as a symmetrical α-Fe_2O_3 loop superimposed on a very hard magnetization in one direction.

In no previous case has a reverse thermoremanence and magnetization asymmetry been observed in the same material. Furthermore, since x-ray data[5] show this sample to be a single phase, the explanation used for the α-Fe_2O_3-$LaFeO_3$ system cannot be applied indiscriminately to Co_2VO_4. A simple interpretation of the observed effects has been formulated on the basis of the various interactions that occur in this material and the known magnetic hardness of Co^{2+} on spinel octahedral sites.[6] However, a detailed understanding of the behavior requires more accurate knowledge of the various magnetic interactions than is now available. To obtain this information, a systematic substitution of nonmagnetic cations for cobalt and vanadium is now under way.

N. Menyuk
K. Dwight, Jr.
D. G. Wickham

2. Magnetic Form Factors

Currently, two neutron diffractometers are under construction for use at the Institute nuclear reactor. On completion these instruments will be used for the investigation of neutron scattering by magnetic materials. One of the problems of interest which will be investigated concerns the spatial distribution of the magnetic electrons. This information is uniquely derived from measurements on the angular distribution of the neutron magnetic scattering. A program on this aspect of magnetic scattering, carried out with polarized neutron beams, is in progress at Brookhaven National Laboratory in collaboration with Dr. Pickart of that laboratory and will be continued with Lincoln spectrometers when available. The abstracts of two papers, presented at the 1959 Conference on Magnetism and Magnetic Materials in Detroit, 16-19 November 1959, describe the technique of the polarized beam method and discuss in detail some recent work on the ordered structure Fe_3Al.

R. Nathans

The Precise Measurement of Magnetic Form Factors

by R. Nathans

The use of the polarized-beam technique in obtaining enhanced sensitivity for measurement of small magnetic cross sections is discussed. The basis of the method, the experimental apparatus and procedures, and finally the necessary corrective factors influencing the accuracy of the resulting data, are dealt with in brief.

A summary of magnetic-form-factor measurements on metallic Fe, Ni, f.c.c. and hex. Co are noted together with the more important conclusions based on the experimental results. References are given to the several publications which summarize what has been learned about obtaining polarized beams and adapting them to diffraction purposes, and also to those which give quantitative data on neutron-form-factor measurements to date.

The Magnetic Form Factor of Fe_3Al

by S. J. Pickart and R. Nathans

An accurate determination of the magnetic form factor in ordered Fe_3Al has revealed that the two different iron sublattices in this ordered structure possess different outer-electron distributions. By the adaptation of the polarized-beam techniques to the study of the small magnetic scattering at high angles, it is possible to determine the proper admixture of the magnetic electron

in the doubly degenerate and triply degenerate orbitals. For the iron site which has only iron atoms as nearest neighbors, the e_g orbitals are highly favored. For the iron site surrounded by a tetrahedron of four iron atoms and a tetrahedron of four aluminum atoms, the t_{2g} triply degenerate orbitals are favored. Since the magnetic moments of these two iron sites had been earlier determined to be different, the present data indicated that in this case, at least, the lowering of the transition element moment by near neighbor nonmagnetic atoms is effected by an electronic-transfer mechanism.

R. Nathans

C. Theory

1. Spin Configurations in the Cubic Spinel

Recent work on the problem of spin configurations in spinels is summarized in a paper that was also presented at the Conference on Magnetism and Magnetic Materials. An abstract of the paper is given below.

Classical Theory of Spin Configurations in the Cubic Spinel

by T. A. Kaplan

It was recently pointed out that the Yafet-Kittel triangular spin configurations do not minimize the classical Heisenberg exchange energy in the cubic spinel.[7] A perturbation calculation for determining the ground configuration is described in the present paper. We consider only nearest neighbor A-B and B-B interactions (J_{AB} and J_{BB}), and one spin magnitude, S_A, for the A-sites, one S_B, for the B-sites. The method consists of first determining the largest value, y_o of $y = J_{BB}S_B/J_{AB}S_A$, for which the Néel configuration is stable with respect to sufficiently small spin deviations. One then looks for solutions of the extremum equations as power series in $(y - y_o) \geqslant 0$, such that the spin deviations from the Néel configuration are small when $y - y_o$ is small. The detailed calculations lead to the following conclusions: (1) Equilibrium configurations exist which have, simultaneously, nonzero angles between spins on the A-sites and between those on the B-sites. (2) The ground state in the cubic spinel will probably be a long-range-ordered canted-spin arrangement, for at least some finite range of $y - y_o$. The significance of these conclusions in connection with experiments on $MnCr_2O_4$ and Mn_3O_4, and with Anderson's remarks concerning spin configurations in spinels, is discussed.

2. Direct Cation-Cation Interactions

An article entitled "On the Direct Cation-Cation Interactions in Several Oxides" has been written and submitted to the Physical Review. This work was also reported at the Conference on Magnetism and Magnetic Materials in conjunction with the experimental work of S. Foner and P. Carr of Group 82 on the paramagnetic susceptibility of single crystals of Ti_2O_3 and V_2O_3, and the x-ray work of E. Warekois of Group 84 on V_2O_3. A summary of some of the experimental evidence for direct cation-cation (as opposed to cation-anion-cation) interactions is presented in Table 53-II. The most favorable configuration for such interactions is one where cation-occupied octahedra share a common octahedral face as in the corundum and NiAs-type

TABLE 53-II

SOME PHYSICAL PROPERTIES OF A FEW TRANSITION ELEMENT COMPOUNDS

Structure at High T	Compound	n_{2g}	$n_b(m)$	ρ (ohm-cm) $T = T_t^+$	Cooperative Transition			T_N, T_C (°K)	Magnetic Order at Low T	Noncooperative Transition			References
					T_t (°K)	Δρ (ohm-cm)	$\Delta\chi/\chi$ T_t^+			T_1, T_2 (°K)	Δρ (ohm-cm)	$\Delta\chi/\chi$ T_t^+	
Rocksalt	CrN	3	2(2)	Metal ?	~273	0	~0.6	273	4th kind $\mu^{Cr} = 2.36\mu_B$	–	–	–	a
Rocksalt	VO	3	3?	Metal $10^{-1.9}$	114(c) 126(h)	$\sim 10^6$	?	–?	?	–	–	–	b
Ordered Rocksalt*	$LiVO_2$	2	2?	?	~450	?	~0.75	–?	?	–	–	–	c
Corundum	αFe_2O_3	5	–	Ins $\sim 10^{14}$	–	–	–	948	+–+ on c-axis	~175-253	?	μ-axis changes	d,e f,g
Corundum	Cr_2O_3	3	–	Ins ?	–	–	–	306	+–+– on c-axis	~220-306	?	‡	h,i
Corundum	V_2O_3	2	1(1) 1(1)?	Metal $10^{-1.7}$	153(c) 165(h)	$>10^5$	~0.4	–	No magnetic scatter	380-530	Max ρ ~525°K	Const χ $T_1 < T < T_2$	b,j
Corundum	Ti_2O_3	1	1(1)	Metal $10^{-1.3}$	–	–	–	–	$\mu^{Ti} < 0.5\mu_B$	~300-500	$\sim 10^2$	~0.5	b,k,l
Rutile	VO_2	1	1(1)	Metal $\sim 10^{-2.3}$	~330(c) ~340(h)	$\sim 10^4$	~0.9	–	?	–	–	–	b
Rutile	CrO_2	2	–	Metal† 10^{-2}	–	–	–	394	Ferro. $\mu^{Cr} = 2.07\mu_B$	–	–	–	m,n
Rutile	MnO_2	3	–	?†	–	–	–	~72	Spiral	–	–	–	o,p
Rutile	MnF_2	5	–	Ins $\sim 10^{10}$ (1 kcps)	–	–	–	~84	Cat. subl. antiferro.	–	–	–	o,q,r

Legend: n_{2g} = number of cation t_{2g} electrons; $n_b(m)$ = number of bonding t_{2g} electrons in low-temperature phase and the multiplicity m of bonds in which each bonding electron participates; T_t^+ = temperature just above transition temperature T_t; $T_1 \leqslant T \leqslant T_2$ is temperature interval over which second-order transition takes place; T_N, T_C are Néel and Curie temperatures; $\chi_{T_t^+}$ is magnetic susceptibility just above T_t.

* Hexagonal or rhombohedral symmetry.

† Stoichiometry questionable. Max ρ at T_C or T_N.

‡ Anomalous antiferromagnetic-resonance effects in temperature interval of ~100°C below T_N.

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TABLE 53-III

COMPARISON OF PHYSICAL PROPERTIES TO BE ASSOCIATED WITH CATION-ANION-CATION VS CATION-CATION INTERACTIONS BETWEEN OCTAHEDRAL-SITE CATIONS

Property	Cation-Anion-Cation	Weak Cation-Cation	Strong Cation-Cation
Magnetic Order	(1) Cations on opposite sides of an anion antiferromagnetic (2) Ferromagnetism (see Table 53-I)	(1) Nearest-neighbor cations antiferromagnetic if $n_{2g} \leq 3$ (2) Ferromagnetism (very low T_C) if $n_{2g} > 3$ and t_{2g} level degenerate	(1) Spin pairing between bonded cation pairs if $n_{2g} \leq 3$ (or $n_{2g} \leq 5$ and bonding removes degeneracy). (2) Ferromagnetism if unpaired e_g electrons simultaneously present with (a) $n_{2g} > 3$ and degenerate t_{2g} level, or (b) $5 < n_{2g} < 6$.
Electrical Conductivity	Semiconductor (or insulator)*		Metallic. May become semiconductor at low T.†
Cation Magnetic Moment	$\mu_{eff}^2 \propto S(S+1)\mu_B^2$; $\mu \propto S\mu_B$ with S the same at low and high T and predictable from knowledge of occupation of isolated-cation d levels, Δ, and E_{ex}.		$\mu_{eff}^2 \propto S(S+1)\mu_B^2$; $\mu \propto S'\mu_B$ with $S > S'$, where S' is net cation spin in low-T phase.‡
Phase Change§	Jahn-Teller or spin-orbit type. Possible if m = 1, 2, 4, 6, 7, 9 (m = 4, 9 are Jahn-Teller and the strongest). Characteristic: Alteration of anion-octahedron symmetry, but cation in center of symmetry.		Bond-formation type. Possible if $n_{2g} \leq 5$. Characteristic: Cation-cation pairing that shifts cation from center of symmetry of anion interstice.

Legend: T is temperature, T_C Curie temperature, μ_{eff} effective paramagnetic cation moment, S net cation spin, μ_B Bohr magneton, μ ferromagnetic or antiferromagnetic cation moment, Δ ligand-field splitting, E_{ex} exchange splitting, and n_{2g} is number of t_{2g} electrons per cation.

* Exceptions: (1) If cations of same element, but different valence, are simultaneously present, material may have a metallic-type σ-T character below a ferromagnetic Curie temperature. (2) If m = 4, the occupied e_g levels may overlap the conduction band.

† If all available t_{2g} electrons participate, at low T, in covalent-type cation-cation bonds, semiconductor. If no bond formation or if not all half-filled t orbitals participate in bond formation, remains metallic at low T.

‡ If low-T phase a semiconductor, $S' \rightarrow 0$ (unless unpaired e_g electrons are present); if low-T phase a metal, $(S - S') = nf$ where f = fraction (~ 0.5) and n = number of electrons per cation participating in bond formation. Only at high T ($T \gg T_N$) is entropy sufficiently important to induce S to approach the value predicted from a knowledge of d-level occupation, Δ, and E_{ex}.

§ Cooperative if lattice symmetry changed; noncooperative transitions may extend over a range of temperature ($\Delta T \sim 100°C$).

TABLE 53-IV

SPIN-SPIN INTERACTIONS BETWEEN HIGH-SPIN-STATE, OCTAHEDRAL-SITE CATIONS

Λ	Interaction*	m_1	m_2	J	$T_{C,N}$ [°K]	Remarks
No. 1 or No. 2	Cat-cat	0 $\leqslant 5$ $5 < m < 8$ $8 \leqslant m \leqslant 10$	$\leqslant 10$ $\leqslant 5$ < 8 10	0 – + 0	0 $\lesssim 500$ < 50† 0	$T_{C,N}$ decreases with increasing R, Z. "Strong" interactions may form "bonded" cation pairs below T_N with physical consequences given in Table 53-II. Cat-an-cat assumed negligible since $\alpha \approx 90°$.
$\alpha = 180°$	Cat-an-cat	0 $\leqslant 3$ $4 \leqslant m \leqslant 8$ 4 $4 \leqslant m \leqslant 8$ 10	$\leqslant 10$ $\leqslant 3$ $\leqslant 3$ 4 $5 \leqslant m \leqslant 8$ $\leqslant 10$	0 – + ‡ – 0	0 ~100 $\lesssim 300$ ‡ ~750 0	$T_N \sim \frac{z}{27k} \frac{(S+1)}{S} \frac{\Delta^2}{U} \zeta$ if $5 \leqslant m_{1,2} \leqslant 8$ and spin-orbit coupling negligible; $T_{N,C}$ reduced by about factor of ten if m_1 or $m_2 \leqslant 3$.[a] Both σ and π bonding symmetric about anion. Cat-cat cannot occur.
$\alpha \sim 120°$	Cat-an-cat	0 $\leqslant 3$ $4 \leqslant m \leqslant 8$ 4 $4 \leqslant m \leqslant 8$ 10	$\leqslant 10$ $\leqslant 3$ $\leqslant 3$ 4 $5 \leqslant m \leqslant 8$ $\leqslant 10$	0 ± – ‡ – 0	0 ~100 $\lesssim 300$ ‡ ~750 0	Similar to case $\alpha = 180°$ except that bonding on opposite sides of cation is no longer symmetric.[b]

Legend: Λ symbolizes relative orientations of anion octahedra about interacting cations: No. 1 = common octahedral face, No. 2 = common octahedral edge, α = common octahedral corner with cation-anion-cation angle α. The two cations have outer-electron configurations nd^{m_1}, nd^{m_2}, and J is the exchange constant, + indicating ferromagnetic coupling, – antiferromagnetic coupling, 0 no (or paramagnetic) coupling. The estimated magnetic-ordering temperature $T_{N,C}$ is for oxides of transition elements of the first long period as obtained from empirical data: these are to be modified in accordance with the qualifying remarks. R and Z are the cation-cation separation and cation atomic number, respectively.

* Table assumes degenerate t_{2g} level. If octahedral site distorted by electron ordering within t_{2g} or e_g levels, degeneracy is removed and each interaction (i.e., along different crystallographic directions) must be considered separately, though according to the same principles.

† Assumes weak interactions and degenerate t_{2g} levels.

‡ Two situations possible: (1) occupied e_g levels overlap conduction band giving ferromagnetism ($T_C > 300°K$) with $\mu < 4\mu_B$/cation and metallic-type conductivity; (2) cooperative Jahn-Teller distortion results in antiferromagnetic interactions between some cation pairs, ferromagnetic or negligible interactions between others (see Ref. 7).

a. See Ref. 3. Δ is ligand-field splitting, S cation spin, z number of coupled cation neighbors, k Boltzmann's constant, ζ a measure of the fraction of covalence in the cation-anion bond, and U is the intra-atomic Coulomb energy required to shift an electron from one cation to another given each cation initially has the correct number of electrons.

b. Magnetic coupling follows from physical arguments set forth in Ref. 6 together with consideration of total geometric relationship.

structures, but these interactions also occur if cation-occupied octahedra share a common edge. Cation-anion-cation interactions occur if cation-occupied octahedra share a common corner. It is further pointed out that if the cation-cation separation is small, the interacting electrons are best described by a collective-electron model, but if it is large, by a Heitler-London approximation. Since there is a critical cation-cation separation between these two descriptions, it is possible to classify the direct cation-cation interactions as "strong" or "weak" in a natural way. The physical consequences of these interactions are summarized in Table 53-III and the conditions for and characteristics of cation-cation vs cation-anion-cation interactions are summarized in Table 53-IV.

J. B. Goodenough

III. MAGNETIC FILMS

A. Origin of Magnetic Anisotropy

A model has been developed which unifies a considerable body of experimental data obtained for Permalloy films. This model and additional investigations into the microorigin of oblique-incidence anisotropy were reported at the Conference on Magnetism and Magnetic Materials, Detroit, 16-19 November 1959. The abstracts of these papers are given below.

Anisotropy and Inversion in Permalloy Films

by D. O. Smith, E. E. Huber, Jr., M. S. Cohen and G. P. Weiss

A phenomenological model of field-induced and oblique-incidence anisotropy in Permalloy films is proposed. It is assumed that the field-induced structure does not introduce any local spatial dispersion in the macroscopic magnetization M; the opposite is assumed for oblique-incidence structure. In addition it is assumed that the oblique-incidence dispersion is anisotropic, being least when M is perpendicular to the depositing beam.

Support for the model comes from anisotropies, found for oblique-incidence films only, in the following measurements: resonance line width, transmission of polarized light and resistivity. A primary success of the model is the prediction of a correlation between anisotropy and inversion ($H_w/H_k > 1$). Inverted films can be made by crossing the field-induced and oblique-incidence anisotropies at 90°. Such films exhibit a "locked" state in which opposite rotation of M in local regions occurs; this implies centers of spatial dispersion and provides the connection with oblique-incidence anisotropy.

A method of inducing anisotropy by means of a moving substrate is described. The assumption of local dispersion is shown to apply to this type of anisotropy also. Finally, a guide to understanding the interdependence of H_k and H_w is given in terms of the anisotropy model: field-induced structure does not have any effect on H_w, while oblique-incidence structure can be a primary determinant for H_w.

Investigations Into the Origin of Anisotropy in Oblique Incidence Films

by M. S. Cohen, E. E. Huber, Jr., G. P. Weiss and D. O. Smith

Experimental evidence is presented which shows that the magnetic anisotropy of oblique-incidence Permalloy and iron films is not caused by an inclined texture axis or anisotropy strain. Electron diffraction and microscopy have

not yet revealed anisotropy in the crystalline microstructure of these films. These techniques have also thus far failed to reveal the existence of agglomeration of the crystallites into small groups having anisotropic geometric shapes. Magnetic anisotropy, on the other hand, was observed in Permalloy films deposited at normal incidence on nonmagnetic metal films deposited at oblique incidence; this would suggest such an agglomeration mechanism. There is also some indication that oxygen may play a role in oblique-incidence magnetic anisotropy.

B. Initial Susceptibility

A study of the initial susceptibility of Permalloy films was also given at this conference and the abstract is as follows.

Initial Susceptibility of Permalloy Films

by R. F. Soohoo

The initial susceptibility of Permalloy films from 100 to 10,000 Mcps is investigated theoretically and experimentally. The exact boundary value problem, excluding exchange effects, of a film filling the entire cross section of a rectangular cavity is solved. The spatial distribution of the magnetic field within the film is then determined from the results of the exact solution to show that the neglect of the exchange term in the equation of motion of the magnetization is justified when the thickness of the film is smaller than the skin depth over the frequency range considered. It was shown further that the exact solution reduces to that obtained from perturbation theory when the thickness of the film is smaller than about 0.4 its skin depth. This sets the limits of validity of the perturbation theory for this or other film-cavity geometries. It is seen from Fig. 53-2 that the experimental values of the initial susceptibility agree very well with the theoretical prediction.

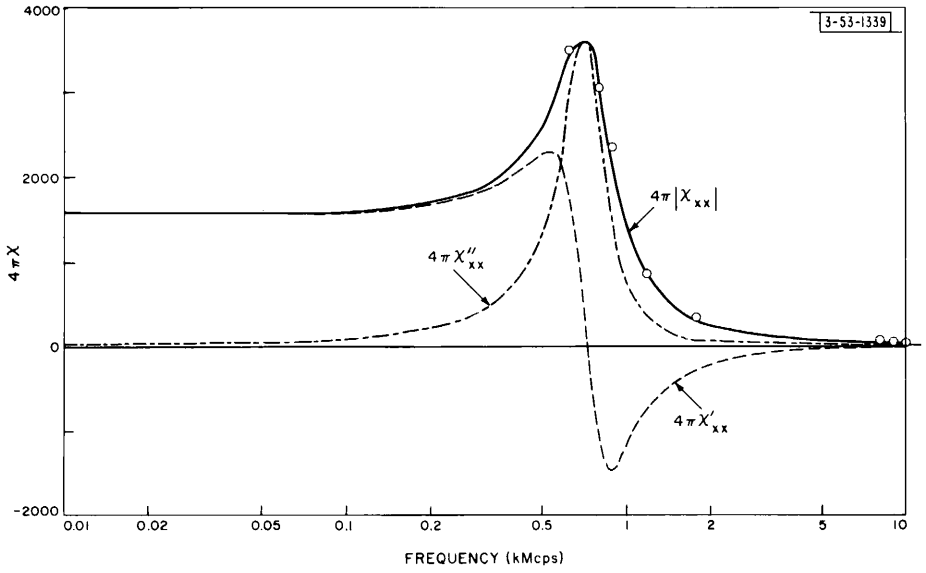

Fig. 53-2. Initial susceptibility of a typical Permalloy film vs frequency. The constants of the film are: $4\pi M = 9875$ oe, $\gamma = 2.91$ Mcps-oe, $\lambda = 1.59 \times 10^{-8}$ rad/sec, $H_k = 6.3$ oe, $\zeta = 21 \times 10^{-6}$ ohm-cm, and $\delta = 1200$ Å. Note that circled points represent experimental values of $4\pi|\chi_{xx}|$.

C. Flux Reversal by Noncoherent Rotation

A theoretical study of the noncoherent mode of rotational flux reversal in Permalloy films was also presented at the Conference on Magnetism and Magnetic Materials.

Flux Reversal by Noncoherent Rotation in Magnetic Films

by K. J. Harte

A model of magnetization reversal in thin ferromagnetic films is proposed. The model is based on a small angular dispersion ($\sim 3°$) of the axis of planar anisotropy in the film plane. The dynamical effects of this dispersion are important when the switching field (H_s) is of the order of the anisotropy field (H_k), fall off rapidly with increasing H_s, and include a twofold-to-threefold increase in the switching coefficient. In addition, it is shown that the transverse flux reaches its maximum before the longitudinal flux is half-switched. These results are in reasonable agreement with experiment for bias field $H_\perp$ large enough to insure unidirectional rotation.

IV. SEMICONDUCTING COMPONENTS

A. Cryosar Circuits

A random-access cryosar memory was proposed in August and much of the quarter was spent on its development. A simplified circuit is shown in Fig. 53-3. The decoder matrix on the left consists of 2^n n-way "and" gates and converts an n-bit binary address into the desired location. It is able to pass both negative- and positive-going pulses due to the symmetry of the cryosar diode. The memory diode is the double-break device described in the Quarterly Progress Report on Solid State Research for 15 April 1959, page 11.

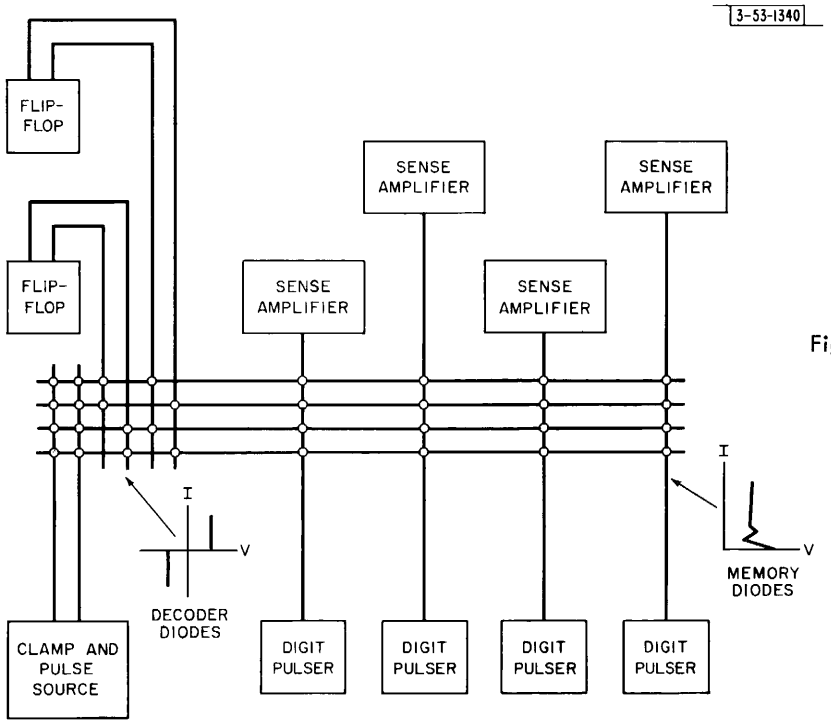

Fig. 53-3. Random-access memory.

C. UHF Switching-Transistor Development

Work in this area has been largely preliminary. The aim is to obtain a switching transistor capable of operating with rise times of about 1 mμsec for use in a future 50-Mcps computer.

A fundamental problem associated with this study is instrumentation. Previous transistor test sets are not usable and perhaps even some of the parameters are inapplicable. As a first step, numerous 100- to 200-Mcps transistors have been measured on the General Radio 1607A transfer-function bridge. These measurements give plots of complex α as a function of frequency from 50 to 1500 Mcps. Results obtained with this bridge have led to a decrease in the collector load of our simple f_t test to 10 ohms, making this instrument capable of reading values up to about 300 Mcps with reasonable accuracy. A Lumatron model 12-AB sampling scope has also been set up to measure pulse-response times.

Philco Corporation has already supplied 50 special, high-frequency amplifiers and 50 high-frequency switches. Some units with f_t values as high as 900 Mcps have been measured on the GR bridge. A number of proposals for switch designs have been received from device manufacturers.

D.J. Eckl

D. VHF Transistor Switching Theory (f_t Degradation with Current at High Current Densities)

It is fairly well known that the common-emitter, short-circuit, current gain-bandwidth product, f_t, of a transistor exhibits a fall-off with increasing collector current at high current densities ($\sim$1000 amp/cm^2). A theory relating the fall-off of high-frequency performance with increasing current at high current densities to a space charge build-up in the collector depletion layer has been developed during this quarter.

According to the theory, a minority carrier space charge accumulates in the collector depletion layer region with increasing collector current. At a sufficiently high current density, the minority carrier space charge builds up to a value such that its density can no longer be considered negligible in comparison with the fixed charge density of the ionized impurities in the depletion region. In accordance with Poisson's equation, this situation leads to an increasing E-field with collector current and, for a given collector voltage, to a decrease in the depletion layer width with current. The subsequent widening of the base layer results in a reduction of the gain-bandwidth product with current.

Theoretical expressions for the high-frequency fall-off with current have been derived from the theory and compared with the observed behavior. The resultant agreement between the theoretical and experimental data appears good enough to lend considerable validity to the space charge theory.

C.T. Kirk

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PATTERN RECOGNITION
GROUP 54

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PATTERN RECOGNITION
GROUP 54

I. INTRODUCTION

Two pandemonium models are progressing: the character recognition study is currently reporting 90 per cent success on badly drawn characters and this percentage should rise soon; a Morse code pandemonium is being reprogrammed for the first hierarchical pandemonium studies.

MAUDE is undergoing extensive operational testing and is not reported this quarter. The degarble program is being expanded to handle a larger vocabulary.

There are two abstract learning studies in progress: one on hill-climbing, and another on "neuron" nets.

A new section is called "linguistic studies" and includes "baseball," a study being undertaken jointly with Group 58.

O. G. Selfridge

II. MAUDE

A. Degarble

Ninety test messages have been made up for use in evaluation of the degarble program. They contain both character and word-space errors. The word-space errors are irrelevant to the performance of the program because all word spaces are eliminated before processing and the message is treated as a string of letters. The messages have from zero to nine per cent character error.

In all runs to date, the program has been able to reconstruct word boundaries correctly in messages that do not contain character errors. A small number of word boundary errors occur in messages containing garbles. Analysis of character corrections has not been completed. However, with three per cent character error, 55 per cent to 65 per cent of the errors are corrected and negative corrections are introduced at the rate of 2 per cent to 3 per cent. The variation in the percentage of errors corrected is a function of the character correction thresholds used. The optimum values for these thresholds are being determined.

At about the seven per cent level the character correction percentage begins to decrease substantially. As the scope of the program increases and more complicated errors can be corrected, it is hoped to raise the percentage of corrections at the various garble levels.

A separate program is being written to process an arbitrary vocabulary and produce tables needed for degarbling. As soon as this is completed, work will begin with a larger and more practical vocabulary, probably of one thousand words.

Martha W. Evens
Constance K. McElwain
Mary A. Wilkes

III. LEARNING

A. Pandemonium Studies

1. Character Recognition

Six or seven hundred additional samples of hand-printed characters have been processed into formats acceptable to the character recognition program. This has made possible a more significant test than the earlier trial reported. Because over two-thirds of the 918 samples at hand were in the ten classes A E I L M N O R S T, no attempt was made to try the scheme for any other characters.

The program is currently organized as in Fig. 54-1. (A few new tests have been added and the 709 program rearranged to use less time.) The processing and testing are carried out and the results organized into tables. The tables are then subjected to some arithmetic and to reorganization to produce the census. This is a set of tables which for each separate test and test result gives estimates of the probabilities that an unknown is each of the possible characters. It is this information that is extracted when the results of testing an unknown are fed into the compare box. Decision is made by forming weighted sums of these inverse probabilities over all the tests and guessing the unknown to be that character whose sum is greatest.

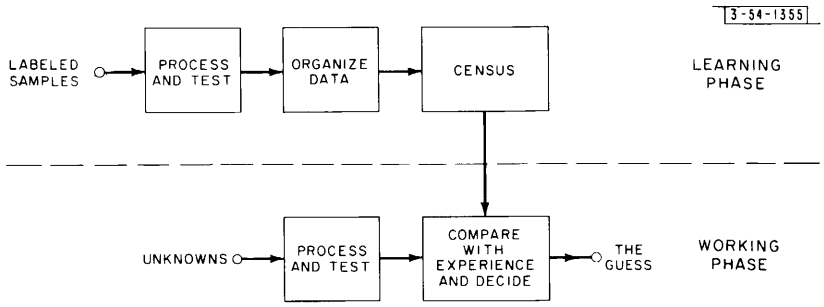


Fig. 54-1. Arrangement of pattern recognition scheme.

To try the scheme, the stock of 635 samples (total) of the 10 characters was divided into two parts containing about half the samples of each character. The first half was fed to the learning phase and its census used to try to recognize the other half as unknowns in the working phase. As all the unknowns were processed, the results were noted and summarized in a confusion matrix. This was done again with roles of labeled samples and unknowns reversed. Table 54-I is a composite of the two confusion matrices produced. The number in row r and column c is the fraction of time that character r was guessed to be character c. The overall success is about 87 per cent.

Some suggested improvements in the decision process are being worked on. Figures 54-2 and 54-3 include most of the A's and R's available as samples.

W. L. Doyle

TABLE 54-I
CONFUSION MATRIX FOR AEILMNORST

	A	E	I	L	M	N	O	R	S	T
A	.733		.014	.013	.041	.078		.122		
E		.944	.011					.011	.023	.011
I			.937	.020					.042	
L			.154	.805						.042
M			.021		.894	.085				
N					.128	.835	.018			.019
O					.016	.033	.935	.016		
R	.062	.031			.431	.016		.845		.015
S		.028	.100						.845	.028
T			.040							.960

-54-1356

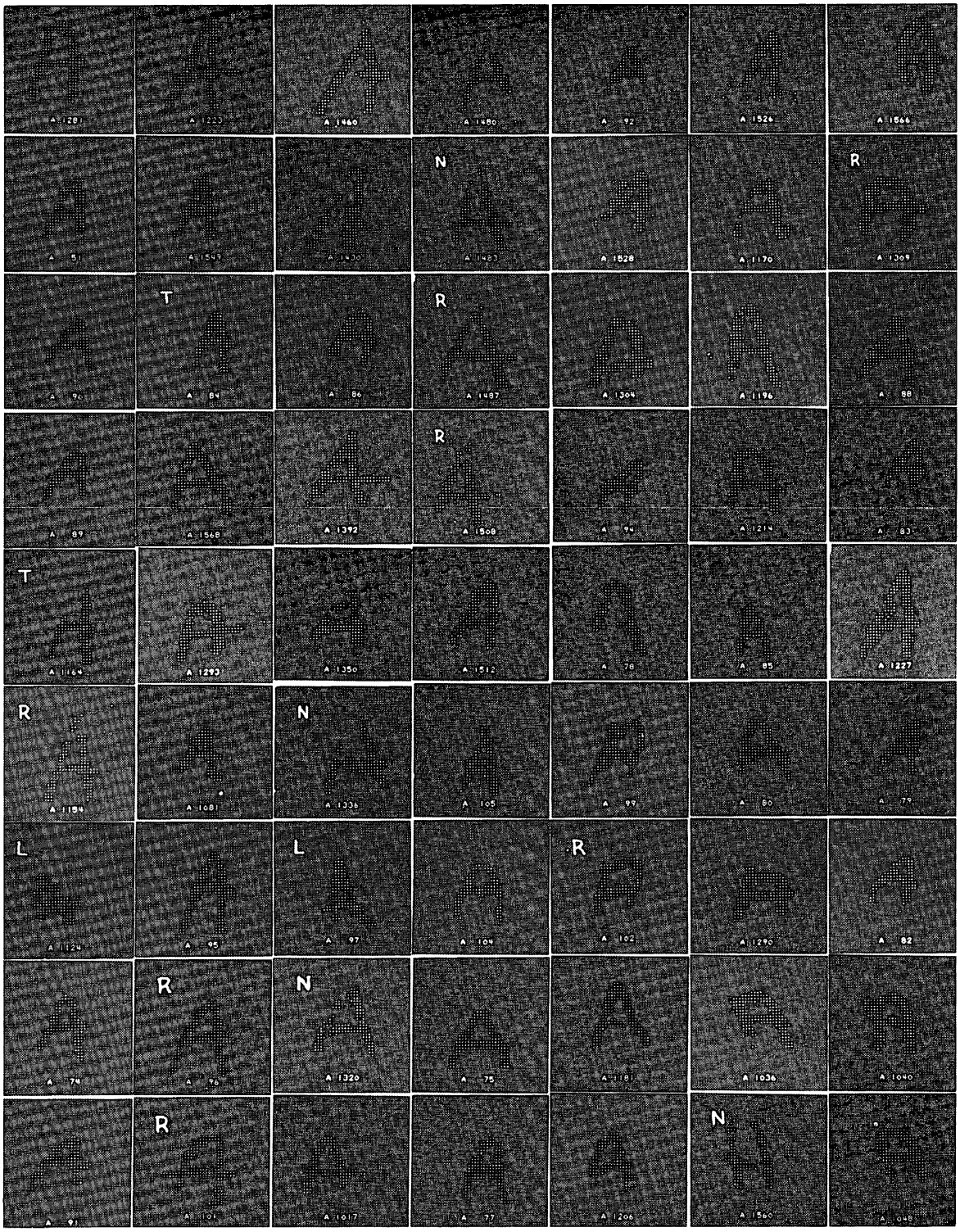


Fig. 54-2. Samples of letter A.

-54-1357

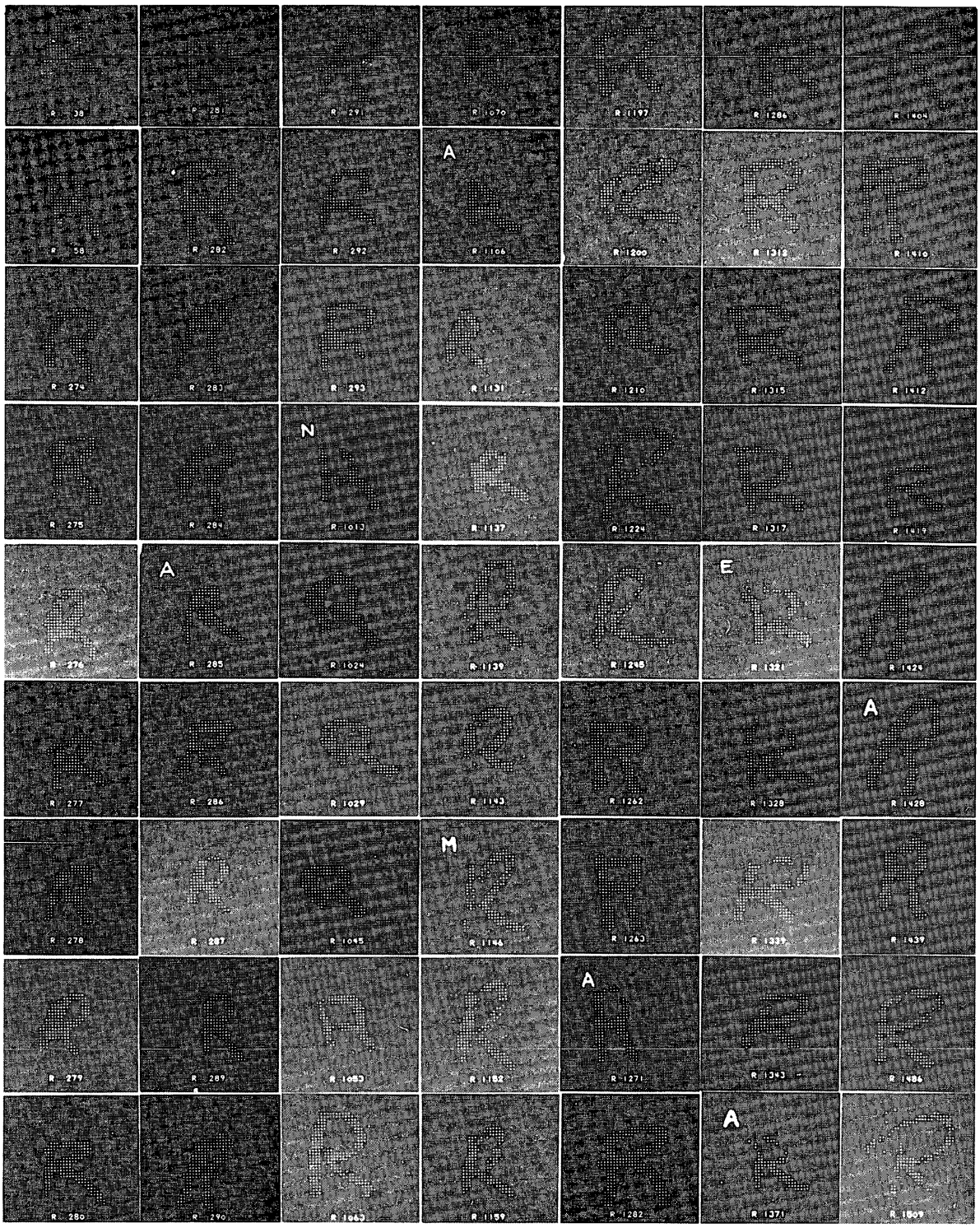


Fig. 54-3. Samples of letter R.

2. Morse Translator

a. Introduction

We have been programming a Morse code pandemonium.* Since most Morse code operators, skilled and unskilled, depart a good deal from school-book rules for sending, no simple algorithm exists for decoding their messages.†‡§ Our decoding scheme is shown in Fig. 54-4. Several levels of "demons" perform various computations on the data. The decision is made by picking the largest output from the set of "cognitive" demons.

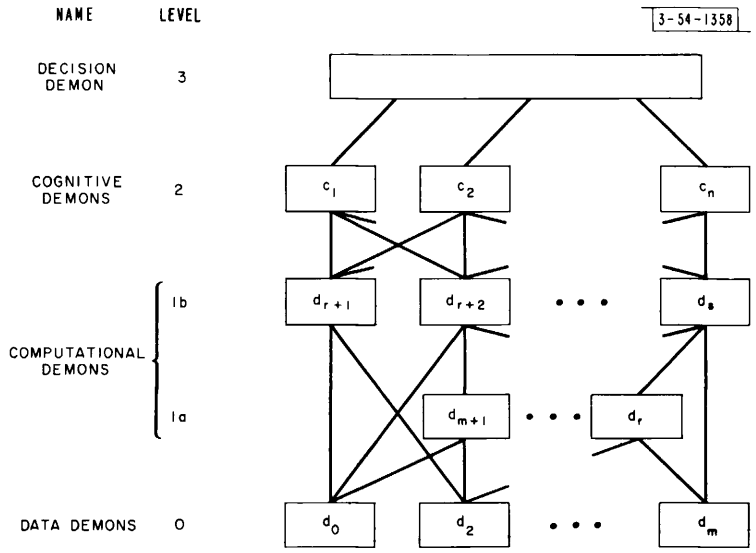


Fig. 54-4. General pandemonium.

b. Mark Recognition

Our initial goal is to distinguish dots from dashes. We are given the durations (in msec) of alternating marks and spaces

$$d_0\ ,\ d_1\ ,\ \ldots,\ d_{19}\ ,\ d_{20}\ ,\ d_{21}\ ,\ \ldots,\ d_{40}$$

mark, space, . . . , space, mark, space, . . . , mark,

where d_{20} is the mark under consideration. The durations take steps of two from right to left as time passes. Thus the current d_{22} will be the next d_{20}, i.e., the next mark to be recognized is d_{22}.

From the structure and statistics of Morse code we have extracted three types of computational demons whose outputs are useful in distinguishing between dots and dashes. All of these make use of the ratio demon, which we shall describe first. Ratio $(d_i, d_j; a)$ compares

* O. Selfridge, "Pandemonium: A Paradigm for Learning," Symposium on Mechanization of Thought Processes, National Physical Laboratory, Teddington, England, 24-27 November 1958.

† B. Byrnes, et al., "Some Results of the MAUDE Program," Group Report 34-72, Lincoln Laboratory, M.I.T. (June 1958).

‡ B. Eisenstadt, et al., "MAUDE," Group Report 34-57, Lincoln Laboratory, M.I.T. (April 1957).

§ B. Gold, "Machine Recognition of Hand Sent Morse Code," Trans. I.R.E. PGIT IT-5, 17 (1959).

d_i/d_j with the number a, producing an output +1 if they are nearly equal, +0.5 if they are somewhat equal, and 0 otherwise. More specifically, it produces an output based on $a/(d_i/d_j) = ad_j/d_i$, as shown in Fig. 54-5.

We are now prepared to describe the three types of useful demons.

(1) Direct-Comparison Demons:— Morse code rules specify that a dash should be exactly three times as long as a dot. Hence if we divide d_{20} by another mark, say d_0, and the result is approximately 3, then we have evidence that d_{20} is a dash (and d_0 a dot). Ratio $(d_{20}, d_0; 3)$ is used for this direct comparison. Since there are twenty marks (other than d_{20}), we can have twenty of these dash-seeking direct-comparison demons. All of these demons belong on level 1b in Fig. 54-4.

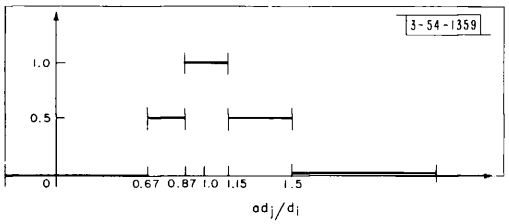


Fig. 54-5. Ratio $(d_i, d_j; a)$.

If the ratio d_{20}/d_0 is near 1, we may suppose that both marks are dots or both are dashes. Since this does not yield any information about d_{20} alone, we do not make use of it.

If, however, d_{20}/d_0 is near .33, then we have evidence for d_{20}'s being a dot. This leads to using ratio $(d_{20}, d_0; .33)$ as a dot-seeking direct-comparison demon, of which type we also have twenty.

Since spaces come in sizes comparable to those of marks, we could also make use of such demons as ratio $(d_{20}, d_1; 3)$ for dash-seeking, and ratio $(d_{20}, d_1; .33)$ for dot-seeking. We note, however, that the durations of spaces vary from their ideals even more than the marks.

It is important to note that the outputs of the direct-comparison demons are occasionally incorrect, e.g., d_{20} might be a relatively short dash and d_0 a relatively long one, thus producing a spurious positive output for the dot-seeking demon ratio $(d_{20}, d_0; .33)$.

(2) Comparison with Maximum (or Minimum) Demons:— Since dashes are usually longer than dots, if we choose the largest of a sequence of marks and at least one of these marks was a dash, then we will, in fact, have chosen a dash. Let

$$d_{41} = \max[d_0, d_2, \ldots, d_{20}] \quad ;$$

then d_{41} presumably has output equal to the duration of a dash. If we now find that the ratio d_{41}/d_{20} is near 1, we may suppose that d_{20} is also a dash. Thus ratio $(d_{41}, d_{20}; 1)$ is a dash-seeking demon. We would place d_{41} on level 1a of Fig. 54-4, since it performs an intermediate computation. Ratio $(d_{41}, d_{20}; 1)$ belongs on level 1b.

We can produce a whole family of demons similar to those just described. We let

$$d_{42} = \max[d_2, d_4, \ldots, d_{22}] \quad ,$$

$$\vdots$$

$$d_{51} = \max[d_{20}, d_{22}, \ldots, d_{40}] \quad ,$$

and form the comparison demons ratio $(d_{42}, d_{20}; 1), \ldots,$ ratio $(d_{51}, d_{20}; 1)$. Use of these demons leaves us open to error if d_{20} is part of a sequence of eleven consecutive dots (e.g., "this story" and "the ship" have 12 and 15 consecutive dots, respectively). We could avoid this by using

just one comparison demon, based on $\max[d_0, d_2, \ldots, d_{40}]$, since it is rather unlikely that twenty-one consecutive dots occur ("this is his ship" has 32). However, this would make it difficult to identify d_{20} correctly as a dash if it is rather short and any one of the other marks is a long dash.

If we similarly define

$$d_{52} = \min[d_{10}, d_{12}, \ldots, d_{20}] \quad ,$$

$$\vdots$$

$$d_{57} = \min[d_{20}, d_{22}, \ldots, d_{30}] \quad ,$$

and perform the comparisons ratio $(d_{52}, d_{20}; 1), \ldots,$ ratio $(d_{57}, d_{20}; 1)$, then we have a series of dot-seeking demons. We use only six consecutive marks here since we are not so much troubled by six consecutive dashes ("the motto of" has 13) as by very short dots obscuring the longer ones.

(3) Comparison with Average Demons:— Morse code is so constructed that when ordinary English text is sent, 40 per cent of all marks are dashes and 60 per cent are dots. If it is supposed that dashes will be three times as long as dots, the average mark is $.4 \times 3 + .6 \times 1 = 1.8$ times as long as a dot. If we compute the average of our twenty-one marks

$$d_{58} = \frac{d_0 + d_2 + \ldots + d_{40}}{21} \quad ,$$

then two values of the ratio d_{58}/d_{20} are of interest to us. If d_{58}/d_{20} is near 1.8 we may suppose d_{20} is a dot; ratio $(d_{58}, d_{20}; 1.8)$ is then a dot-seeking demon. If d_{58}/d_{20} is near .6, we may suppose d_{20} is a dash; ratio $(d_{58}/d_{28}; .6)$ is the corresponding dash-seeking demon.

We have found that using ratio $(d_{58}, d_{20}; 1.5)$ and ratio $(d_{58}, d_{20}; 2.1)$ as additional dot-seeking demons produces good results. Similarly, ratio $(d_{58}, d_{20}; .5)$ and ratio $(d_{58}, d_{20}; .7)$ are useful as additional dash-seeking demons.

Demon d_{58} is assigned to level 1a of Fig. 54-4; the various ratio demons go on level 1b.

c. Experimental Results

In our example there are only two categories, dot and dash, and so only two cognitive demons c_{dot} and c_{dash}. In computing their outputs we made use of the fact that anything subtracted from c_{dot} could just as well be added to c_{dash}, and vice versa. Hence c_{dot} need be fed only the positive evidence of the dot-seeking computational demons, and not also the negative evidence of the dash-seekers. Similarly for c_{dash}. Had we three (or more) categories, as in the space identification problem in Morse code, we would not have been able to use only positive evidence.

For c_{dot} we fed in the outputs of twelve direct-comparison demons, each weighted (multiplied) by +1, six comparison-with-minimum demons with weights +2, and three comparison-with-average demons with weights +4. This gave each of the three types of demons equal weight in making decisions. For c_{dash} we used twelve direct-comparison demons with weights +1, six comparison-with-maximum demons with weights +2, and three comparison-with-average demons with weights +4.

By using ten samples of 360 marks and 360 spaces each, this pandemonium was able to recognize 99.76 per cent of the marks correctly. This is about the same as a human decoder,

not making use of context, would do. We then computed two scores for each of the 42 computational demons (on level 1b). This score consisted of the sum of the output when d_{20} was a dot, and the sum for d_{20}, a dash. These scores enabled us to compute the relative effectiveness of the various demons. We found, for example, that comparison-with-maximum and comparison-with-average were the best dash-seeking demons, and that comparison-with-minimum and some direct comparisons were the best dot-seekers. (This last fact contains the unexpected result that some direct comparisons are far more effective than others.)

With these scores, we assigned new weights for calculating c_{dot} and c_{dash}, the most effective demons being given the largest weights. The resulting pandemonium was then tested on the three data samples previously leading to the most errors (0.59 per cent). Only one error was corrected, improving the score to 0.49 per cent.

d. Future Plans

We have not achieved perfect dot-dash discrimination, even after adjusting the weights given to the various computational demons by the cognitive demons. It seems necessary to make some use of context in decoding, which will involve recognizing letters and perhaps even words. As a first step we are engaged in distinguishing among the three types of spaces: symbol, letter and word. We have found that the three types of demons described above can be used quite successfully in solving this problem. However, the output furnished by the ratio demon is somewhat limited in being a two-sided comparison, so we have introduced two new output demons, the maximizer demon (Fig. 54-6) and the minimizer demon (Fig. 54-7). These compare the number a with d_i/d_j, and produce positive outputs if a is larger (maximizer demon) or smaller (minimizer demon) than d_i/d_j.

M. Freimer

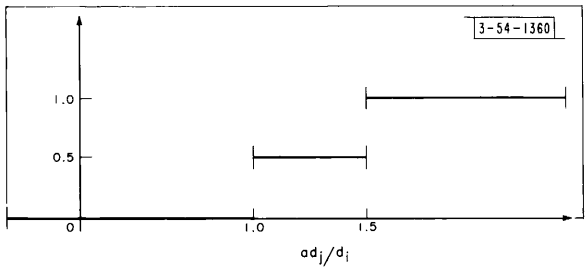


Fig. 54-6. Maximizer $(d_i, d_j; a)$.

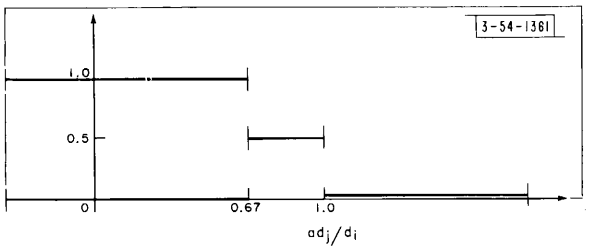


Fig. 54-7. Minimizer $(d_i, d_j; a)$.

B. Hill-Climbing

We have been testing on the computer the mod 3 hill-climber whose behavior is given by

$$\Lambda(t) = \{\lambda_i(t)\} = \{\lambda_i(t-1) + \alpha_i J_i(t)\, S(t-1)\}$$

$$S = S(\{\lambda_i\}) \quad , \tag{1}$$

where the $\{J_i\}$ are orthogonal with mean 0.

An interesting question is whether Eq. (1) is convergent if the J_i are random and independent. The next section suggests that it is not at all convergent, except for the one-dimensional case, and this is borne out by the tests we have run.

On the other hand, if at any time at most one of the J_i is different from zero, Eq. (1) is certainly convergent. That, of course, is equivalent to sequential processing. The speed of convergence then depends crucially on $\{\alpha_i\}$ and the actual function $S(\{\lambda_i\})$. We are exploring these matters further.

M. Minsky
O. G. Selfridge

Let $\lambda(t)$ be the position vector of a point in n-space at (discrete) time t, $S(t)$ its norm, and $\{J(t)\}$ a set of independent unit vectors uniformly distributed in angle.

$$\lambda(t) = \lambda(t-1) + \alpha J(t)\, S(t-1) \tag{2}$$

has been proposed as a possible hill-climbing scheme and we wish to compute the asymptotic distribution of $S(t)$ for this case.

Taking inner products on both sides of the above equation, we get

$$S^2(t) = (1 + 2\alpha \cos\Theta_t + \alpha^2)\, S^2(t-1) \quad ,$$

where Θ_t is the angle between $\lambda(t-1)$ and $J(t)$. Since $J(t)$ is independent of $\lambda(t-1)$, Θ_t is uniformly distributed in $[(0, 2\pi)]$ if $n > 1$ and is 0 or π with equal probability if $n = 1$. We have

$$\log S^2(t) = \log S^2(0) + \sum_1^t \log(1 + 2\alpha \cos\Theta_\tau + \alpha^2) \quad ;$$

and since the independent, identically distributed random variables $\log(1 + 2\alpha \cos\Theta_\tau + \alpha^2)$ have finite mean m and variance σ, if

$$\alpha \neq 1 \quad \frac{\log S^2(t) - \log S^2(0)}{t}$$

converges to m almost everywhere. Hence when $m > 0$, $S^2(t) \to \infty$ almost everywhere and when $m < 0$, $S^2(t) \to 0$ almost everywhere. When $m = 0$, $[\log S^2(t) - \log S^2(0)]/\sqrt{t}$ is asymptotically Gaussian with mean 0 and variance σ. By the zero-one law the probability that $\log S^2(t) - \log S^2(0)$ remains either negative or positive for large values is either 0 or 1 and since these are mutually exclusive, equiprobable sets both have probability 0. Hence, in this case, $\liminf S^2(t) = 0$ and $\limsup S^2(t) = \infty$ with probability 1.

The values of m are:

$n = 1 \quad m = \frac{1}{2}[\log(1-\alpha)^2 + \log(1+\alpha)^2]$

$= \frac{1}{2}\log[(1-\alpha^2)^2]$ $\quad < 0$ if $0 < \alpha < \sqrt{2}$, $\alpha \neq 1$

$= 0$ if $\alpha = \sqrt{2}$

> 0 if $\alpha > \sqrt{2}$.

$n = 2 \quad m = \frac{1}{2\pi}\int_0^{2\pi} \log(1 + 2\alpha \cos\Theta + \alpha^2)\, d\Theta$

$= 0$ if $0 < \alpha < 1$

$= \log \alpha^2 > 0$ if $1 < \alpha$.

$$n > 2 \quad m = \left(\frac{1}{2\pi}\right)^n \int_0^{2\pi} \cdots \int_0^{2\pi} \log(1 + 2\alpha \cos\Theta_1 \cdots \cos\Theta_n + \alpha^2)\, d\Theta, \ldots, d\Theta_n$$

$$> \left(\frac{1}{2\pi}\right)^n \int_0^{2\pi} \cdots \int_0^{2\pi} \log[1 + 2(\alpha \cos\Theta_1 \cdots \cos\Theta_{n-1}) \cos\Theta_n$$

$$+ (\alpha \cos\Theta_1 \cdots \cos\Theta_{n-1})^2]\, d\Theta_1 \cdots d\Theta_n$$

$$\geqslant 0 \quad \text{if} \quad \alpha \neq 1 \quad .$$

The case $\alpha = 1$ seems much more difficult.

All this suggests that random independent jitters will not be successful in hill-climbers governed by Eq. (2).

T. S. Pitcher

C. Learning in Random Nets

We are studying the learning process by which a random net acquires some (desired) organization which exhibits itself as an ability for pattern recognition or data processing.

We may suppose that initially the net shows no success at all and that the final success is preceded by states less successful which are reinforced by some direct or indirect mechanism. These intermediate states of the net are termed Precursors. The first phase of net activity must be to find the first Precursor, which is the first state that is detectably more successful. This first phase we term Errant Trial.

The second phase is Hill-Climbing, on the ground that from the first Precursor appropriate small and reinforceable changes may monotonically improve success and lead to ultimate complete success.

Thus the nature and action of the reinforcement mechanism can affect only Hill-Climbing, and have no effect on Errant Trial, except as it may perhaps determine whether a possible Precursor is detectable or not. The time needed for Errant Trial clearly depends on the number of states to be explored and the number of detectable Precursors. In case the total number of possible states is finite, we may give some fairly accurate bounds on search times. If it is not (or if it is greater than, say, 10^{20}) then the search time depends on the geometry of the phase space of net states including Precursors. For a given net one can easily construct behavior unattainable in a reasonable time.

These notions are being applied to several examples:

(1) To classify binary functions of not more than several variables as (a) accessible and inaccessible (accessible functions have a large number of precursors); (b) remote, or not (remote functions must be approached through long chains of precursors); (c) simple and compound (compound functions are generally inaccessible, but may be a binary function of accessible functions, and hence may be accessible through them).

(2) To analyze the precursors, and their detectability, of some geometric and topological categories in the plane: e.g., an edge, a corner, connectedness.

(3) To analyze elementary arithmetic as an aim for random nets.

On preliminary examination, it seems that most "interesting" problems are compound, in the sense above.

O. G. Selfridge
M. Minsky

IV. LINGUISTIC STUDIES

A. Decryptor

Decryptor is a 709 computer program which automatically decodes English messages enciphered by simple substitution. It works by making an initial guess at a decipherment of the crypt, and then improving this guess until it arrives at a decipherment which is maximally English-like.

Its criterion for Englishness derives entirely from statistical information concerning the English language; specifically, bigram frequencies. No other notion of English structure is available to the program.

It is instructive to regard the process of improving the initial guess by successive steps as a hill-climbing procedure over a terrain. The plan of the terrain is the space of possible keys or ciphers, i.e., the 27! permutations of the 26 English letters plus word space (blank). A sort of topology is imposed on this space by introducing a notion of neighborhood. Two keys are neighbors if (regarded as permutations) they differ at just 2 letters, e.g., the two keys illustrated below. The elevation over a given point or key is the fit, a joint statistic of the original crypt and the given key (see below).

TWO NEIGHBORING KEYS

L	A B C D E F G H I J K L MN O P Q R S T U V W X Y Z b
Key 1(L)	N R V Z C Ⓖ K O S W b D H L Ⓟ T X A E I M Q U Y B F J
Key 2(L)	N R V Z C Ⓟ K O S W b D H L Ⓖ T X A E I M Q U Y B F J

The program chooses an initial key according to one of six schemes. The terrain is explored to determine whether any of the 351 = (26 × 27)/2 neighbors of the present point is higher in elevation. If not, the initial key is used to produce the final solution. If so, a step is taken to the neighbor producing the largest improvement, and the exploration is resumed. Thus the explorer moves up the gradient until it comes to a peak.

At the present time the six starting schemes are as follows: method one produces the identity key and is used to check out the program and to provide a basic method from which to measure the utility of the others. Method two forms the initial key on the basis of symbol frequencies: the most frequent crypt symbol is keyed to the most frequent English letter, namely, blank. The next most frequent crypt symbol is keyed to E, etc. Methods 3 through 6 are essentially algorithmizations of what is known as the "vowel-line" method of solving simple substitution ciphers, and variations thereof.

At the present time, the hill-climbing procedure operates successfully, as do the first two starting schemes. The remaining four are being debugged.

A number of examples are given below. First, it is to be observed that the starting point produced by method 2, letter frequencies, is essentially independent of the initial encipherment of the message since the frequencies with which the various letters occur is not affected by encryptment, e.g., if the most frequent letter in the original text was T, and the encrypting of the text mapped T into say B, then B will be keyed to blank.

The qualification "essentially" is necessary because if two symbols occur with the same frequency in the message, their key assignments will depend on their alphabetic order.

EXAMPLE 1

CRYPT-
A LITTLE SWALLOW STAYED BY THE BANK OF A STREAM HE HAD FALLEN IN LOVE WITH THE MOST BEAUTIFUL FLOWER AND HAD LET ALL THE OTHER SWALLOWS FLY OFF TO EGYPT WITHOUT HIM THIS FRIENDSHIP HAD LASTED ALL SUMMER BUT NOW THAT HIS FRIENDS HAD GONE HE BEGAN TO FEEL LONELY THE FLOWER NO LONGER PLEASED HIM SHE COULD N-OT TALK HE SAID AT LAST THE LITTLE SWALLOW DECIDED TO FLY AWAY AND JOIN HIS FRIENDS HE FLEW OFF TOWARD-THE CITY ABOVE THE CITY STOOD THE STATUE OF THE HAPPY PRINCE HE WAS GILDED WITH THIN LEAVES OF GOLD H-IS EYES WERE TWO BRIGHT SAPPHIRES AND A RED RED RUBY SHONE FROM THE HANDLE OF HIS SWORD WHEN THE LITTL-E SWALLOW ARRIVED AT THE CITY AS THE SUN WAS SETTING HE SAW THE STATUE OF THE HAPPY PRINCE I WILL STAY HERE FOR THE NIGHT HE SAID THIS IS A GOOD PLACE AND THERE IS PLENTY OF FRESH AIR AS HE WAS GOING TO S-LEEP A DROP OF WATER FELL ON HIM THAT IS STRANGE HE THOUGHT THERE ARE NO CLOUDS THE STARS ARE BRIGHT W-ITH THAT ANOTHER DROP FELL AND ANOTHER THE LITTLE SWALLOW LOOKED UP THE EYES OF THE HAPPY PRINCE WERE FILLED WITH TEARS AND TEARS WERE RUNNING DOWN HIS CHEEKS

INITIAL KEY-
ABCDEFGHIJKLMNOPQRSTUVWXYZ
OPYLECWARJVNBDIMXHSTGKUZFQ

MESSAGE-
O NRTTNE SUONNIU STOFEL PF TAE PODV IC O STHEOB AE AOL CONNED RD NI E URTA TAE BIST PEOGIRCGN CNIUEH ODL AOL NET ONN TAE ITAEH SUONNIUS CNF ICC TI EWFMT URTAIGT ARB TARS OHREDLSARM AOL NOSTEL ONN SGRBEH PGT DIU TAOT ARS CHREDLS AOL WIDE AE PEWOD TI CEEN NIDENF TAE CNIUEH DI NIDWEH MNEOSEL ARB SAE YIGNL D-IT TONV AE SORL OT NOST TAE NRTINE SUONNIU LEYRLEL TI CNF OUOF ODL JIRD ARS CHREDLS AE CNEU ICC TIUOHL-TAE YRTF OPIKE TAE YRTE STIIL TAE STOTGE IC TAE AOMNF MHRDYE AE UOS WRNLEL URTA TARD NEO ES IC WINL A-RS EFES UEHE TUI PHRWAT SOMMARHES ODL O HEL HEL HGPF SAIDE CHIB TAE AODLNE IC ARS SUTHL UAED TAE NRITN-E SUONNIU OHHRKEL OT TAE YRIF OS TAE SGD UOS SETIRDW AE SUU TAE STOIGE IC TAE AOMMF MHRDYE R URNN STOF AEHE CIH TAE DRWAI AE SORL TARS RS O WIIL MNOYE ODL TAEHE RS MNEDTF IC CHESA URH OS AE UOS WIRDW TI S-NEEM O LHIM IC UOTEH CENN ID ARB TAOT RS STHODWE AE TAIGWAT TAEHE OHE DI YNIGLS TAE STOHS OHE PHRWAI U-RTA TAOT ODITAEH LHIM CENN ODL ODITAEH TAE NRTTNF SUONNIU NIIVEL GM TAE EFES IC TAE AOMMF MHRDYE UEHE CRNNEL URTA TEOHS ODL TEOHS UEHE HGDDRDW LIUD ARS YAEEVS

FIT = 1.4850

TRIAL 9

FIT IMPROVED BY INTERCHANGING KEY(I)=O WITH KEY(O)=J

KEY-
ABCDEFGHIJKLMNOPQRSTUVWXYZ
APFDEGWHIJVLBNOMXRSTUKCZYQ

DFIT = .012923

FIT = 1.0532
A LITTLE SCALLOC STAYED PY THE PANV OG A STREAB HE HAD GALLEN IN LOKE CITH THE BOST PEAUTIGUL GLOCER AND HAD LET ALL THE OTHER SCALLOCS GLY OGG TO EWYMT CITHOUT HIB THIS GRIENDSHIM HAD LASTED ALL SUBBER PUT NOC THAT HIS GRIENDS HAD WONE HE PEWAN TO GEEL LONELY THE GLOCER NO LONWER MLEASED HIB SHE FOULD N-OT TALV HE SAID AT LAST THE LITTLE SCALLOC DEFIDED TO GLY ACAY AND JOIN HIS GRIENDS HE GLEC OGG TOCARD-THE FITY APOKE THE FITY STOOD THE STATUE OG THE HAMMY MRINFE HE CAS WILDED CITH THIN LEAKES OG WOLD H-IS EYES CERE TCO PRIWHT SAMMHIRES AND A RED RED RUPY SHONE GROB THE HANDLE OG HIS SCORD CHEN THE LITTL-E SCALLOC ARRIKED AT THE FITY AS THE SUN CAS SETTINW HE SAC THE STATUE OG THE HAMMY MRINFE I CILL STAY HERE GOR THE NIWHT HE SAID THIS IS A WOOD MLAFE AND THERE IS MLENTY OG GRESH AIR AS HE CAS WOINW TO S-LEEM A DROM OG CATER GELL ON HIB THAT IS STRANWE HE THOUWHT THERE ARE NO FLOUDS THE STARS ARE PRIWHT C-ITH THAT ANOTHER DROM GELL AND ANOTHER THE LITTLE SCALLOC LOOVED UM THE EYES OG THE HAMMY MRINFE CERE GILLED CITH TEARS AND TEARS CERE RUNNINW DOCN HIS FHEEVS

TRIAL 16, NO IMPROVEMENT MADE

KEY-
ABCDEFGHIJKLMNOPQRSTUVWXYZ
ABCDEFGHIJKLMNOPXRSTUVWZYQ

FIT = .9681

MESSAGE-
A LITTLE SWALLOW STAYED BY THE BANK OF A STREAM HE HAD FALLEN IN LOVE WITH THE MOST BEAUTIFUL FLOWER AND HAD LET ALL THE OTHER SWALLOWS FLY OFF TO EGYPT WITHOUT HIM THIS FRIENDSHIP HAD LASTED ALL SUMMER BUT NOW THAT HIS FRIENDS HAD GONE HE BEGAN TO FEEL LONELY THE FLOWER NO LONGER PLEASED HIM SHE COULD N-OT TALK HE SAID AT LAST THE LITTLE SWALLOW DECIDED TO FLY AWAY AND JOIN HIS FRIENDS HE FLEW OFF TOWARD-THE CITY ABOVE THE CITY STOOD THE STATUE OF THE HAPPY PRINCE HE WAS GILDED WITH THIN LEAVES OF GOLD H-IS EYES WERE TWO BRIGHT SAPPHIRES AND A RED RED RUBY SHONE FROM THE HANDLE OF HIS SWORD WHEN THE LITTL-E SWALLOW ARRIVED AT THE CITY AS THE SUN WAS SETTING HE SAW THE STATUE OF THE HAPPY PRINCE I WILL STAY HERE FOR THE NIGHT HE SAID THIS IS A GOOD PLACE AND THERE IS PLENTY OF FRESH AIR AS HE WAS GOING TO S-LEEP A DROP OF WATER FELL ON HIM THAT IS STRANGE HE THOUGHT THERE ARE NO CLOUDS THE STARS ARE BRIGHT W-ITH THAT ANOTHER DROP FELL AND ANOTHER THE LITTLE SWALLOW LOOKED UP THE EYES OF THE HAPPY PRINCE WERE FILLED WITH TEARS AND TEARS WERE RUNNING DOWN HIS CHEEKS.

EXAMPLE 2

INITIAL KEY-
ABCDEFGHIJKLMNOPQRSTUVWXYZ
ABVDEFGHIQXLZNOPURSTKJWCYM

FIT = 1.0659

MESSAGE-
A LITTLE SWALLOW STAYED BY THE BANX OF A STREAZ HE HAD FALLEN IN LOJE WITH THE ZOST BEAKTIFKL FLOWER AND HAD LET ALL THE OTHER SWALLOWS FLY OFF TO EGYPT WITHOKT HIZ THIS FRIENDSHIP HAD LASTED ALL SKZZER BKT NOW THAT HIS FRIENDS HAD GONE HE BEGAN TO FEEL LONELY THE FLOWER NO LONGER PLEASED HIZ SHE VOKLD N-OT TALX HE SAID AT LAST THE LITTLE SWALLOW DEVIDED TO FLY AWAY AND QOIN HIS FRIENDS HE FLEW OFF TOWARD-THE VITY ABOJE THE VITY STOOD THE STATKE OF THE HAPPY PRINVE HE WAS GILDED WITH THIN LEAJES OF GOLD H-IS EYES WERE TWO BRIGHT SAPPHIRES AND A RED RED RKBY SHONE FROZ THE HANDLE OF HIS SWORD WHEN THE LITTL-E SWALLOW ARRIJED AT THE VITY AS THE SKN WAS SETTING HE SAW THE STATKE OF THE HAPPY PRINVE I WILL STAY HERE FOR THE NIGHT HE SAID THIS IS A GOOD PLAVE AND THERE IS PLENTY OF FRESH AIR AS HE WAS GOING TO S-LEEP A DROP OF WATER FELL ON HIZ THAT IS STRANGE HE THOKGHT THERE ARE NO VLOKDS THE STARS ARE BRIGHT W-ITH THAT ANOTHER DROP FELL AND ANOTHER THE LITTLE SWALLOW LOOXED KP THE EYES OF THE HAPPY PRINVE WERE FILLED WITH TEARS AND TEARS WERE RKNNING DOWN HIS VHEEXS

EXAMPLE 3

```
TRIAL  16. NO IMPROVEMENT MADE.

    KEY-
ABCDEFGHIJKLMNOPQRSTUVWXYZ
LPFNXBAKUQIRVYD TMOZJCWSHGE

FIT =   1.0788

    MESSAGE-
EY BLARIE BRNDED ENAKIEITIVEAVEMIZZEAVEALOVENERES NGE

   CRYPT-
ELLEN WAS DISAPPOINTED IN HIS PUB WHICH COULD HAV
```

EXAMPLE 4

```
   MESSAGE-
ALLAN WES DISEFFOINGAD IN HIS FUR WHITH TOULD HEC

   CRYPT-
ELLEN WAS DISAPPOINTED IN HIS PUB WHICH COULD HAVE BEEN THE COCKTAIL BAR OF THE TECUMSEH HOTEL IN J

   MESSAGE-
ERREN WAS DISALLOINTED IN HIS LUM WHICH COURD HAVE MEEN THE COCKTAIR MAY OF THE TECUGSEH HOTER IN B

    CRYPT-
 ELLEN WAS DISAPPOINTED IN HIS PUB WHICH COULD HAVE BEEN THE COCKTAIL BAR OF THE TECUMSEH HOTEL IN JOR-
DAN SHE HAD VAGUELY EXPECTED SOMETHING RAFTERED

    MESSAGE-
 ERREN WIS DASIPPOANTED AN HAS PUM WHACH COURD HIVE MEEN THE COCKTIAR MIL OF THE TECUBSEH HOTER AN JOL-
DIN SHE HID VIGUERY EXPECTED SOBETHANG LIFTELED

    CRYPT-
 ELLEN WAS DISAPPOINTED IN HIS PUB WHICH COULD HAVE BEEN THE COCKTAIL BAR OF THE TECUMSEH HOTEL IN JOR-
DAN SHE HAD VAGUELY EXPECTED SOMETHING RAFTERED AND SMOKY WITH BEER AND HE TOLD HER TO KEEP IT QUI

    MESSAGE-
 ELLEN WAS DISAPPOINTED IN HIS PRB WHICH CORLD HAZE BEEN THE COCKTAIL BAM OU THE TECRVSEH HOTEL IN JOM-
DAN SHE HAD ZAGRELY EXPECTED SOVETHING MAUTEMED AND SVOKY WITH BEEM AND HE TOLD HEM TO KEEP IT FRI

    CRYPT-
 ELLEN WAS DISAPPOINTED IN HIS PUB WHICH COULD HAVE BEEN THE COCKTAIL BAR OF THE TECUMSEH HOTEL IN JOR-
DAN SHE HAD VAGUELY EXPECTED SOMETHING RAFTERED AND SMOKY WITH BEER AND HE TOLD HER TO KEEP IT QUIET F-
ROM THE ROYAL FAMILY AND THE PRIME MINISTER BU

    MESSAGE-
 ELLEN WAS DISAPPOINTED IN HIS PUB WHICH COULD HAVE BEEN THE COCKTAIL BAR OF THE TECUMSEH HOTEL IN JOR-
DAN SHE HAD VAGUELY EXPECTED SOMETHING RAFTERED AND SMOKY WITH BEER AND HE TOLD HER TO KEEP IT QUIET F-
ROM THE ROYAL FAMILY AND THE PRIME MINISTER BU
```

EXAMPLE 5

```
   CRYPT
HE HAD PUT THE GUN BACK

    INITIAL KEY IS
ABCDEFGHIJKLMNOPQRSTUVWXYZ
ABCDEFGHIJKLMNOPQRSTUVWXYZ

   MESSAGE
HE HAD PUT THE GUN BACK

NO IMPROVEMENT MADE.

TRIAL NUMBER  6 COMPLETED.

    KEY IS
ABCDEFGHIJKLMNOPQRSTUVWXYZ
AWCNEFOHIJKLMSGBURDTUVPXYZ

   CRYPT
HE HAD PUT THE GUN BACK

   MESSAGE
HE HAN BUT THE OUS WACK
```

Because of this independence, it was unnecessary to encrypt the test messages for method 2. In example 1, the text is excerpted from "The Happy Prince," by Oscar Wilde. The text was presented to the program without encipherment. Method 2 produced the initial key shown at A. The first line of letters represents the symbols of the crypt. The second line represents the English letters keyed to them by the key. The 27^{th} symbol, blank, occurs, at the right-hand end of each line, printed as ' '. The corresponding decipherment of the message is shown at B. The "fit" shown at C is a normalized

$$\text{fit} = \frac{\log p}{\log p_0} \quad ,$$

where p is the probability that the solution at any point was generated by a Markov process governed by the transition probabilities of English, and p_0 the expected value for a message of a given length. We want to minimize it, and so will expect it to approximate unity for English messages. To divert the reader (not to deflect him), an intermediate stage in the hill-climbing is reproduced. After nine steps, the key, fit and decipherment shown at D were achieved. Finally, after 15 steps and a total time of 221 sec, the hill was successfully climbed, with the results shown at E.

Example 2:— The superiority of a vowel-line method over that of letter frequencies can be seen in example 2, which is the initial guess generated by method 3 on the same text. The right answer appeared after six steps and 91 seconds.

Example 3:— The shorter the crypt, the harder the job. The text for this example came from the Saturday Review. It shows the program at its worst. Note that it confuses the space character.

Example 4:— This example shows the way performance improves with increasing text length.

Example 5:— Is the identity key for a clear English text a peak? Often it is not. The likelihood of "yes" clearly increases with message length. The example shows how short messages can be corrupted by the hill-climbing process.

R. L. Silver

B. Baseball

A computer program is being designed that will be capable of finding, in a bank of data stored in the computer, the answer to a question fed into the computer in ordinary English. As explained in the Division 5 Quarterly Progress Report for 15 September 1959, the context in which the program will operate is baseball scores. The program includes a linguistic part that ascertains from the English question just what information is being asked for, and an information retrieval part that finds the answer in the stored data. The program is divided into four main sections.

(1) A rudimentary syntactic analysis of the question, which furnishes information needed in (2).

(2) A content analysis of the question, which sets up a list specifying the data relevant to the question, and a list of the processes to be performed on that data to obtain the answer.

(3) A search through the data, which locates the specified information.

(4) A data-processing operation, which determines the answer to the question.

The limited syntactic analysis performed in (1) omits many features ordinarily considered to be an integral part of linguistic analysis, since the program needs to meet only the specific demands of part (2). It appears that an adequate syntactic analysis must at least identify the subject, verb and object of each clause in the question, and distinguish questions requiring a yes-no answer from all other types of questions.

We have greatly reduced the complexity of the syntactic analysis needed by placing certain fairly simple restrictions on the questioner. These restrictions apply only to questions containing more than one clause (i.e., more than one verb). Complete freedom of order and wording is permitted in questions containing only one clause. The restrictions on multiple-clause questions are:

(1) The main clause must come first.

(2) Subsequent clauses must follow one after the other and not be nested, i.e., no subclause (bracketed below) may occur within another clause. Thus we can handle (a) but not (b).

  (a) Did the Red Sox lose by more than 6 runs [when they played on July 6^{th}]?

  (b) Did the team [that played the Red Sox on July 6^{th}] win by more than six runs?

(3) Subclause boundaries must be marked.

These restrictions allow us to use an analysis program capable of handling only one clause – a vastly simpler program than one that must handle several clauses simultaneously. The program merely analyzes the clauses one at a time, in succession. Other means are also being considered for simplifying the problem further for our initial programming attempt.

The syntactic analysis has been partly programmed in flow chart form. When the flow charts have been completed, we will then program the content analysis of the question. These programs will not be coded until more is known about the availability of several programming languages useful for handling language input.

Carol Chomsky
Alice K. Wolf (Group 58)

V. MISCELLANEOUS

A. A Diode Circuit for Ranking and Ordering Sets of Voltages or Currents

Given a set of voltages $[E_n]$, the circuit shown in Fig. 54-8 may be constructed using 2N diodes and other passive components to have a staircase current-voltage characteristic composed of N equal current steps or jumps, the positions of which on the voltage axis correspond to the voltages of the set $[E_n]$. Such a diode circuit is the basis for several scale-of-N counter circuits, and has also been used by Philbrick to commutate the set $[E_n]$ for simultaneous oscilloscopic presentation; the diode circuit is biased with a sawtooth current sweep and the signals are thereby sampled in the order of increasing positive voltage – different baselines may be used to identify the different channels.

The same staircase diode circuit, if biased with a direct current, will transmit the R^{th} most positive voltage of the set; here R may be any index from 1 to N, depending on the choice of bias current. If $N = 2r - 1$, the r^{th} most positive voltage will be the median value of the set. Applications of a median value determining circuit include the generation of odd harmonics (the circuit is excited by N phases of a sine wave), and an analog error correction circuit (if r or more of N voltages are the same, the median value must equal them).

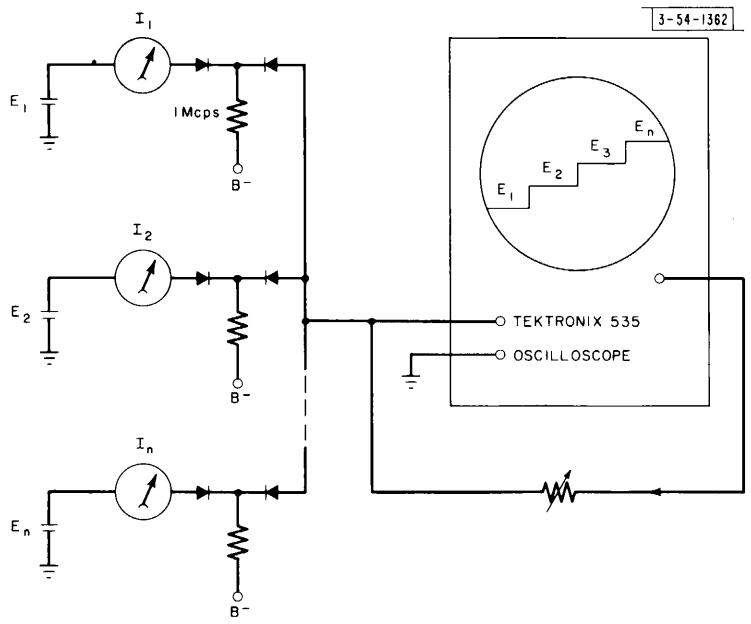


Fig. 54-8. Staircase diode circuit.

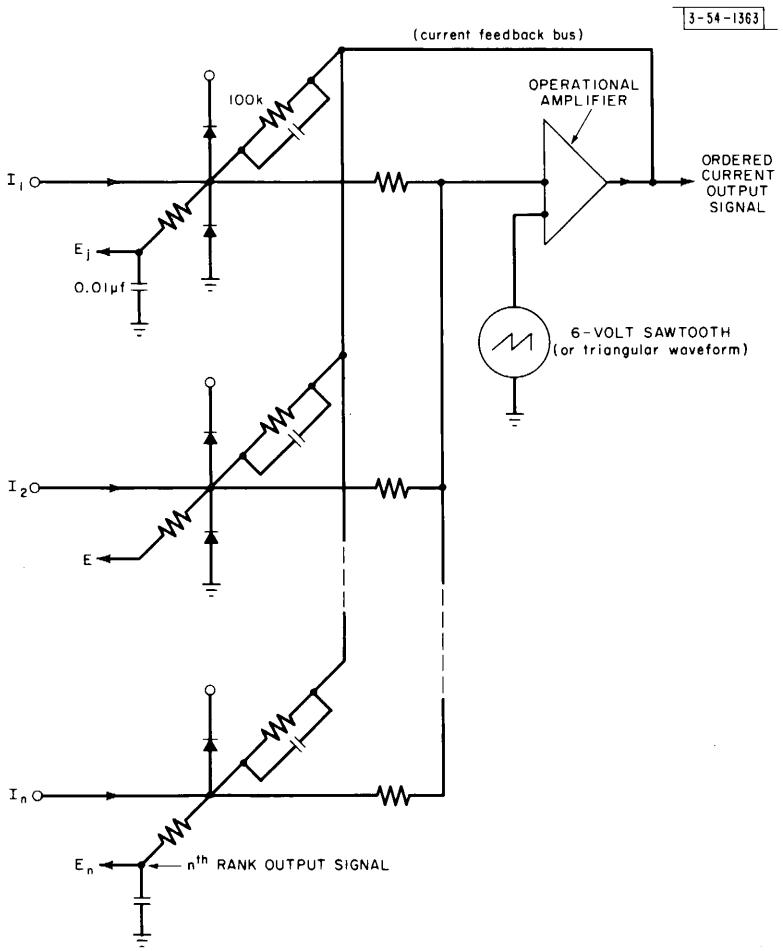


Fig. 54-9. Rank-ordering circuit with voltage outputs.

More generally, a matrix of N differently biased staircase diode circuits with common inputs $[E_n]$ can be used to generate the ordered set of N voltages $[E_j]$; the same result can also be obtained with some loss of speed, but using fewer diodes by decommutating Philbrick's signal. It is important to observe that, with either of these methods of generating the ordered set, the average values of the corresponding set of current supplied to the circuit as, for example, $\{I_n\}$ in Fig. 54-8, will be proportional to the ranks of the input voltages. (An exception occurs when two or more of these voltages are equal, in which case the currents will be equal, and will correspond to an average rank.) Since these currents are inconvenient to measure, it is better to use the dual of the staircase diode configuration, in combination with a sawtooth voltage sweep and current feedback. The dual circuit configuration shown in Fig. 54-9 generates a set of averaged voltages of specified range, proportional to the rank orders of the set of input currents. A commutated, ordered current signal output is also available; this, together with the rank signals, serve to specify the set of input currents.

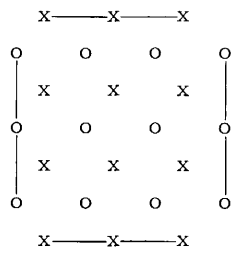
It should be noted that, to each of the photodiodes, the above circuit configuration behaves like a nonlinear load resistance; all such load resistances have, in fact, the same characteristic, determined in detail by the interaction of the set of photocurrents. This suggests an extension for the use for such diode circuits, namely, the generation of a large number of identical nonlinear characteristics of specified form. For this purpose we have only to distribute to the diode circuits via the current feedback bus the appropriate waveform: the diode circuits, by averaging the switched portions of this waveform, generate the separate current-voltage characteristics. The waveform can either be generated by special circuitry, or by scanning with a sawtooth wave a prototype circuit having the desired characteristic. This technique for generating, en masse, nonlinear current-voltage characteristics has other applications in analog computation, and can be used to simplify the staircase diode counting circuits mentioned previously.

B. Howland

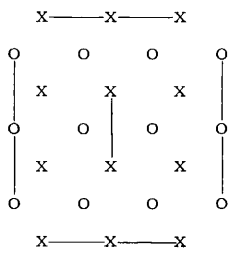
B. A 709 Computer Program to Play the Game of BIRDCAGE

The game is useful to study, since it contains, in a simple accessible form, the elements of very complicated tactics and strategies, such as decision trees, hierarchies of useful subgoals, both real and imputed, and so forth.

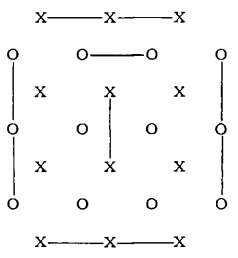
The game is best described by an example. An initial position of the board is shown in diagram 1.



Initial Position of the Board
Diagram 1



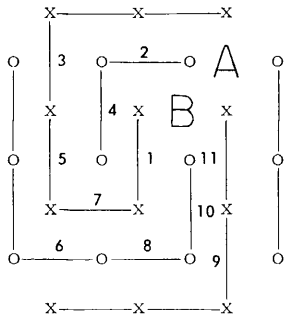
x's First Move
Diagram 2



o's First Move
Diagram 3

There are two players, x and o. Each player strives to connect his two edges with a path formed by line segments. Each player moves in turn by connecting a neighboring pair of his points with a line, provided that the line does not cross a line previously marked by his opponent.

In the example, x moves first as shown in diagram 2; o then acts to block his connection to the top as shown in diagram 3. Moves 3 to 11 are shown in diagram 4. At this point it is o's move, but he cannot prevent x from winning by connecting at either A or B. The game can be played on various size boards. We measure the board size by the number of segments in the shortest possible winning path; 3 in the example. The game is complex and interesting when played on boards of size 6 or above.



Moves 3-11
Diagram 4

Shannon has constructed a simple and ingenious analog computer to play his game on a board of size 6. The idea incorporated in it, recast in digital form, is the heart of our program which has been flow-charted, and is being programmed and coded.

Barbara P. Lucy
R. L. Silver

ANALYSIS GROUP 55

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ANALYSIS
GROUP 55

I. INTRODUCTION

The work of Group 55 has continued along lines outlined in recent quarterly progress reports. A report* has been issued on decoding of error-correcting codes,† with special emphasis on application to the highly efficient Bose-Peterson codes. A further study of decoding is being made. A paper‡ was presented at the Symposium on Ordinary Differential Equations in Mexico City in September, covering some of the results on stability of differential equations reported in the previous quarterly progress report. This work is being continued. Another paper§ was presented at the meeting of the American Mathematical Society in Salt Lake City in September on some results for discrete-time queues, also reported in the previous quarterly progress report. New queueing-theory problems are being studied. In addition to these work is continuing on problems arising from noise theory and satellite orbit determination.

W. L. Root

II. PARALLEL QUEUES WITH A SINGLE SERVER

Work is continuing on coupled discrete-time waiting lines. Results have been obtained for the particular case where two queues, Q_1 and Q_2 are in parallel, and when at any particular time the input and output for Q_1 are operating and Q_2 is quiescent with probability p, or Q_2 is operating and Q_1 is quiescent with probability $q = 1 - p$. The choice of which queue is operating is made for each integral time independently.

We define the following generating functions: let

$$\tilde{G}(x,y,w) = \sum_{a,b,t=0}^{\infty} g(a,b,t)\, x^a y^b w^t/t! \quad ,$$

where $g(a,b,t)$ is the probability that there are a persons in Q_1 at time t and b persons in Q_2 at time t, awaiting service. Let

$$\tilde{G}_1(x,w) = \sum_{a,t=0}^{\infty} g_1(a,t)\, x^a w^t/t!$$

and

$$\tilde{G}_2(y,w) = \sum_{a,t=0}^{\infty} g_2(b,t)\, y^b w^t/t! \quad ,$$

where $g_1(a,t)$ $[g_2(b,t)]$ is the probability that, after $Q_1(Q_2)$ has been operated t times, there are a (b) persons waiting for service. These formulas are known as Borel transforms of the

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* N. Zierler, "Decoding Linear Error-Correcting Codes," Group Report 55-15, Lincoln Laboratory, M.I.T. (22 October 1959).

† Division 5 Quarterly Progress Report, Lincoln Laboratory, M.I.T. (15 September 1959), p. 72.

‡ J.J. Levin and J.A. Nohel, "On a System of Integrodifferential Equations Occurring in Reactor Dynamics," Symposium on Ordinary Differential Equations, Mexico City, 6-13 September 1959.

§ J.R. Kinney, "A First Passage Time Distribution," American Mathematical Society, Salt Lake City, 2-4 September 1959.

formulas appearing in Group Report 55-14 on single server queues. (The initial conditions are suppressed in these formulas.) It has been shown that $\tilde{G}(x, y, w) = \tilde{G}_1(x, pw)\, \tilde{G}_2(y, qw)$. Similar formulas have been developed to describe busy times, etc. This material will appear in Group Report 55-18 (to be published).

Work is also continuing on tandem queues.

J. R. Kinney

III. GLOBAL ASYMPTOTIC STABILITY FOR NONLINEAR SYSTEMS OF DIFFERENTIAL EQUATIONS AND APPLICATIONS TO REACTOR DYNAMICS

1. In Group Report 55-17 conditions are obtained under which all solutions of certain real nonlinear systems of differential equations tend to zero as $t \to \infty$. This study originated in some problems of reactor dynamics; however, the systems investigated are of a quite general nature. Therefore, the results are first given in an abstract setting and then interpreted physically.

Theorem 1 is concerned with the following general form of the Liénard equation

(1) $$\ddot{x} + h(t, x, \dot{x})\, \dot{x} + f(x) = e(t) \qquad (\cdot = d/dt) \quad .$$

Theorem 1. Let the following conditions be satisfied:

(2) $h(t, x, z)$, $f(x)$, $e(t)$ are sufficiently smooth for a local existence and uniqueness theorem to hold for (1) on $0 \leqslant t < \infty;\ -\infty < x,\ z < \infty$.

(3) There exists a constant $k > 0$ such that

$$k \leqslant h(t, x, z) \qquad (0 \leqslant t < \infty; -\infty < x,\ z < \infty) \quad .$$

(4) Given any constant $B > 0$, there exists a constant $K_B > 0$ such that

$$h(t, x, z) \leqslant K_B \qquad (0 \leqslant t < \infty;\ |x|,\ |z| \leqslant B) \quad .$$

(5) Given any constant $B > 0$ there exists a constant $K_B > 0$ such that

$$|f(x_1) - f(x_2)| \leqslant K_B\, |x_1 - x_2| \qquad (|x_1|,\ |x_2| \leqslant B) \quad .$$

(6) $$x\, f(x) > 0 \qquad (x \neq 0) \quad .$$

(7) $$g(x) = \int_0^x f(\xi)\, d\xi \to \infty \quad \text{as} \quad |x| \to \infty \quad .$$

(8) There exists a constant $K > 0$ such that

$$|e(t)| \leqslant K \qquad (0 \leqslant t < \infty) \quad .$$

(9) $$\int_0^\infty |e(t)|\, dt < \infty \quad .$$

Then given any x_0, $\dot{x}_0$ the solution $x(t)$ of (1) satisfying $x(0) = x_0$, $\dot{x}(0) = \dot{x}_0$ exists on $0 \leqslant t < \infty$ and

(10) $$\lim_{t\to\infty} x(t) = 0 \quad , \quad \lim_{t\to\infty} \dot{x}(t) = 0 \quad .$$

An immediate consequence of Theorem 1 is

Corollary 1. If, in addition to the hypothesis of Theorem 1, the condition $e(t) \to 0$ as $t \to \infty$ is also satisfied, then $\ddot{x}(t) \to 0$ as $t \to \infty$.

Theorem 2 is concerned with the system

$$(11)\qquad \begin{cases} \dot{x} = -\sum_{i=1}^{n} a_i z_i \\ \dot{z}_i = -h_i(t, x, z)\, z_i + b_i f(x) + e_i(t) \qquad (i = 1, \ldots, n) \end{cases},$$

where the a_i and b_i are constants and $z = (z_1, \ldots, z_n)$, which for $n = 1$ is essentially (1).

Theorem 2. Let the functions h_i, f, e_i be sufficiently smooth for a local existence and uniqueness theorem to hold for (11) on $0 \leqslant t < \infty$; $-\infty < x, z_i < \infty$. Let the h_i satisfy (3, 4), f (5, 6, 7), and the e_i (8, 9). Furthermore, let the constants a_i, b_i satisfy either

$$(12)\qquad a_i = cb_i, \text{ where } c > 0 \text{ and the } b_i \text{ are arbitrary except that at least one, say } b_j, \text{ is not zero,}$$

or

$$(13)\qquad a_i/b_i > 0 \qquad (i = 1, \ldots, n) .$$

Then given any x_0, z_0 the solution $x(t), z(t)$ of (11) satisfying $x(0) = x_0$, $z(0) = z_0$ exists on $0 \leqslant t < \infty$ and

$$(14)\qquad \lim_{t\to\infty} x(t) = 0 , \quad \lim_{t\to\infty} z(t) = 0 .$$

In (3) $-\infty < z < \infty$ means $-\infty < z_i < \infty$ $(i = 1, \ldots, n)$, and $|z|$ in (4) means $|z| = \Sigma\, |z_i|$.

Theorem 3 is concerned with the system

$$(15)\qquad \begin{cases} \dot{x} = -a_0 y - \sum_{i=1}^{n} a_i z_i \\ \dot{y} = b_0 f(x) + e_0(t) \\ \dot{z}_i = -h_i(t, x, y, z)\, z_i + b_i f(x) + e_i(t) \qquad (i = 1, \ldots, n) \end{cases},$$

where again the a_i and b_i are constants and $z = (z_1, \ldots, z_n)$.

Theorem 3. Let the functions h_i, f, e_i be sufficiently smooth for a local existence and uniqueness theorem to hold for (15) on $0 \leqslant t < \infty$; $-\infty < x, y, z_i < \infty$. Let the h_i satisfy (3, 4), f (5, 6, 7), and the e_i (8, 9). Furthermore, let the constants a_i, b_i satisfy either

$$(16)\qquad \begin{cases} a_i = cb_i, \text{ where } c > 0 \text{ and the } b_i \text{ are arbitrary except that} \\ b_0 \neq 0 \text{ and at least one other } b_i, \text{ say } b_j, \text{ is not zero,} \end{cases}$$

or

$$(17)\qquad a_i/b_i > 0 \qquad (i = 0, \ldots, n) .$$

Then given any x_0, y_0, z_0 the solution $x(t), y(t), z(t)$ of (15) satisfying $x(0) = x_0, y(0) = y_0, z(0) = z_0$ exists on $0 \leqslant t < \infty$ and

$$(18)\qquad \lim_{t\to\infty} x(t) = 0 , \quad \lim_{t\to\infty} y(t) = 0 , \quad \lim_{t\to\infty} z(t) = 0 .$$

Here the range of the variables in (3) is $0 \leqslant t < \infty$; $-\infty < x, y, z_i < \infty$ and the condition in (4) is $0 \leqslant t < \infty$; $|x|, |y|, |z| \leqslant B$.

The dynamic equations for a class of homogeneous nuclear reactors are of the form

$$\dot{u} = -\alpha T \quad , \quad \epsilon \dot{T} = -h(t, u, T)\, T + f(u) + e(t) \quad . \tag{19}$$

In the case of Newton's law of cooling one has

$$h(t, u, T) \equiv 1 \quad , \quad f(u) = \exp[u] - 1 \quad , \quad e(t) \equiv 0 \quad ,$$

with the physical interpretations

u = logarithm of the ratio of the reactor power to the stationary power ($u \equiv 0$ at equilibrium),

T = deviation of the temperature from the equilibrium temperature ($T \equiv 0$ at equilibrium),

ϵ = heat capacity,

$-\alpha$ = ratio of the temperature coefficient of reactivity to the mean life of neutrons.

In (19) h is a heat conduction term and e is a forcing term.

An immediate consequence of Theorem 2 ($n = 1$) is

Theorem 4. Let the functions h, f, e satisfy the hypothesis of Theorem 1, and let the constants α, ϵ satisfy $\epsilon > 0$, $\alpha > 0$. Then given any u_0, T_0 the solution $u(t), T(t)$ of (19) satisfying $u(0) = u_0$, $T(0) = T_0$ exists on $0 \leqslant t < \infty$ and

$$\lim_{t\to\infty} u(t) = 0 \quad , \quad \lim_{t\to\infty} T(t) = 0 \quad .$$

2. The dynamic equations for a class of heterogeneous reactors of $m (m \geqslant 2)$ media are of the form

$$\begin{cases} \dot{u} = -\sum_{j=1}^{m} \alpha_j T_j \\ \epsilon_i \dot{T}_i = -h(t, u, T) \sum_{j=1}^{m} X_{ij}(T_i - T_j) + \eta_i f(u) + e_i(t) \qquad (i = 1, \ldots, m) \quad , \end{cases} \tag{20}$$

where $T = \mathrm{col}(T_1, \ldots, T_m)$. The special case previously studied had

$$h(t, u, T) \equiv 1 \quad , \quad f(u) = \exp[u] - 1 \quad , \quad e_i(t) \equiv 0 \qquad (i = 1, \ldots, m) \quad ,$$

with the physical interpretations

u = logarithm of the ratio of the reactor power to the stationary power ($u \equiv 0$ at equilibrium),

T_i = deviation of the temperature from the equilibrium temperature in the i^{th} medium ($T_i \equiv 0$ at equilibrium),

ϵ_i = heat capacity in the i^{th} medium,

$-\alpha_i$ = ratio of the temperature coefficient of reactivity in the i^{th} medium to the mean life of neutrons,

η_i = fraction of the power generated in the i^{th} medium (physically $\sum \eta_i = 1$),

X_{ij} = thermal conductivity from medium i to medium j (physically $X_{ij} = X_{ji}$).

In (20) h is a heat conduction term and the e_i are forcing terms.

In order to apply Theorem 3 to (20) (it can be shown that Theorem 2 is not applicable here), it is necessary to transform it to the form (15). In Group Report 55-17 it is shown that this can be done under suitable hypotheses.

J.J. Levin
J.A. Nohel*

IV. CODES

By abstracting the essentials (and setting up a general framework for dealing with codes) we (with S. Schatz of Group 52) have generalized the theorem of Slepian-Moore (which says that the coset leaders of any group code may be selected in such a way that any descendant of a coset leader is also a coset leader) to the case of an arbitrary finitely generated Abelian group. In somewhat more detail: given any finitely generated Abelian group A and any subgroup (i.e., code) B, then there exist: a natural norm function w on A, a notion of "descendant" based on w, and an ordering for certain subsets of A, such that a full set $\mathcal{S}$ of representatives may be chosen for the cosets of A/B with the property that: if a $\epsilon \mathcal{S}$ then every descendant of a is in $\mathcal{S}$.

In connection with some phenomena that arise in certain examples of Bose codes, we are in the process of studying perfect codes. Perhaps the most interesting result thus far states that any (nontrivial) triple error-correcting perfect code must be of type (23, 12). Such a code does exist, namely, the Golay-Paige code.

E. Weiss

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PSYCHOLOGY
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PSYCHOLOGY
GROUP 58

I. INTRODUCTION

A major long-range goal continues to be the development of procedures that will enable man to communicate with computers in his own language. Communication with a computer in spoken English requires, first, that the computer be able to recognize spoken words, and, second, that it be able to interpret instructions and queries when phrased in English. Progress is being made on both aspects of the general problem.

The TX-2 programs on speech recognition being carried out with Group 51 have been concerned primarily with vowel recognition. This work is now being extended to include identification of fricatives and nasals. The IBM 709 programs for segmenting connected speech into syllables are also being improved. Use of an 11-bit quantization of the amplitude signal instead of the 6-bit quantization will enable finer discriminations to be made. A new soundproof room has been installed and is now ready for use in making the input recordings and carrying out the intelligibility tests that are a part of these studies.

Work on computer interpretation of English language is being done jointly with Group 54. A program is being written which will enable the IBM 709 computer to answer typewritten questions phrased in normal English. The detailed report of this work appears in the Group 54 section of this quarterly progress report. The program is being written in IPL-V, an information processing language devised by Newell, Shaw and Simon, for handling nonnumeric problems. Development of an IBM 709 version of this language was completed during this reporting period.

Several studies concerned with characteristics of human memory are under way. These studies reflect a growing interest in human memory as a process rather than as a capacity. Other research includes a basic psychophysical study of dark adaptation, for which data collection has been completed, and work on the sampling variability of waiting-time distributions, which has been broadened to include exponential service-time queues as well as the constant service-time queues investigated previously.

II. MAN-MACHINE COMMUNICATIONS

A. Automatic Speech Recognition

A program has been developed which classifies individual 5.5-msec spectral slices with sufficient reliability to permit work to proceed on the next phase of the recognition scheme. The presently admissible classifications are silence, fricative, nasal and vowel. The silence category includes sounds that are too low in amplitude to be sensed by the input equipment together with sounds that, although having adequate amplitude, have spectra that are too smooth to be speech sounds. The fricative classification regularly picks up the strong fricatives such as s and sh, sometimes picks up weak fricatives f and th, and often the plosive portion of stop consonants. The nasal category regularly catches the nasal consonants and also picks up the beginnings and endings of the vocalic portion of stop consonants. Attempts to reliably separate semivowel from vowel spectra have not yet been successful. Fortunately, it appears that such a separation is not necessary at this stage but can be achieved later. Vowels, except for /u/ and /o/, are so classified; /l/ and /r/ might also be classed as vowels; /u/ and /o/, some /l/'s and /r/'s, and most transitions are classed as semivowels.

The segmentation program currently being worked out uses the output of the preliminary classification program together with amplitude, duration and formant-motion information. The goal of this program is to define a sequence of segments which is meaningfully related to the actual speech but does not yet correspond to a phonemic or allophonic segmentation. For example, if the word shot had been spoken (in isolation) into the machine, the segmentation program should produce something like the following segmentation:

(1) A period of silence,
(2) A long fricative segment (the sh),
(3) A segment of vowel with the formants moving (the transition from the sh into the vowel),
(4) A steady vowel segment,
(5) Perhaps another transition segment, depending upon the speaker,
(6) A period of silence.

If the speaker exploded the final t there would be additional segments:

(7) A short fricative segment (the explosion),
(8) Possibly a very short vowel-like segment (aspiration),
(9) A final silence.

Some of the segments defined by a program of this type can presumably be identified directly. For example, the sh and the steady vowel portion of the above example should be recognizable on the basis of their spectral properties more or less in isolation. Work is currently proceeding on programs for classifying such relatively steady-state sounds. The vowel recognition portion of this program is being based on the results of the Whirlwind I vowel recognition program. The program for classifying the fricative and nasal sounds is being developed from information in the literature and from the study of spectra. It is planned to work out the final adjustment of thresholds and weights for these programs by means of a learning program. Attempts are being made to find an organization that could supply us with speech recordings of a large number of words by a large number of speakers for use with this program.

J. W. Forgie (Group 51)
Carma D. Forgie

B. Syllable Segmentation

Work is continuing on development of computer programs for segmenting speech into syllables.

A series of 709 computer programs, as previously reported, have been written which simulate the operation of a speech segmenting device. The programs simulate a device with parallel inputs consisting of the amplitude envelope of the speech wave under several conditions of filtering. These several "envelopes" are, in turn, processed by the programs. Successive samples of the "envelopes" must first have been converted into digital form from the output of an envelope detector, which is a slowly varying DC voltage. The segmentation programs use a 6-bit quantization of the amplitude signal.

During this reporting period the analog-to-digital conversion system of Group 33 became available for use. It uses a Datrac ADC which has a 15-kcps sampling rate for 6-bit samples. To date, one successful conversion into digital form was made of the amplitude envelope of a minute-long speech sample under several conditions of filtering. An IBM 709 program was

written and is now operating which retains every 75th sample, thus giving a sampling rate of 200 samples per second. The preparation of data for input to the segmentation programs is now routine for 6-bit samples. A few problems have come up in the segmentation programs, however, and effort is now being made to make the operation of these programs routine. When this is done, it should provide the first results of the segmentation specifications of these programs. The problem of ripple in the envelope signal, referred to in the last quarterly reporting period (Division 5 Quarterly Progress Report for 15 September 1959), seems to be solved for 6-bit samples by the use of the modified Kron-Hite low-pass filter.

Previous study of the amplitude envelope during vowel-semivowel-vowel combinations of speech sounds suggested that one boundary cue may consist of a change in the slope of the envelope at some time between the two vowels. Although it is not certain at this time exactly how small this change may be, it looks as though a 6-bit quantization may be inadequate to detect it. Hence, work was begun in the last reporting period which would allow the segmentation programs to use data with 11-bit quantization. It was also decided to include in the 11-bit series of programs a number of modifications not used in the 6-bit series. These modifications will provide more flexibility in the definition of features of the envelope.

The problem of ripple may again come up with the 11-bit samples. In anticipation of this, a passive filter with a much sharper cutoff is being adapted to the envelope-extracting equipment. In addition, a cumulative averaging method is used in the 11-bit programs to cope with the conversion error which is expected to be more significant with 11-bit samples. The 11-bit version has been checked out by hand during this reporting period, and is now being checked out on the IBM 709 computer.

An Epsco unipolar amplifier, to be delivered shortly, will allow use of the 11-bit capacity of the Datrac in the Group 33 ADC system.

A. N. Stowe

C. Soundproof Room

Comparison of the performance of the TX-2 programs for the recognition of speech with that of people listening to the same material has been hindered because of lack of an area or room with an ambient noise level sufficiently low. Listening tests conducted thus far have had to be carried out with burdensome precautions to prevent occasional loud noises from reducing the reliability of human responses.

During the present reporting period, an Industrial Acoustics Company Audiometric Examination Room, mod 401, was installed. The examination room is mounted on rubber-in-shear vibration isolators, and has an outside-to-inside attenuation characteristic which rises from 20 db at 50 cps to about 55 db at 5000 cps. The internal resonances of the room are not discernible when speech is the sound source; hence, it will be useful both as a recording room for critical speech material and as an experimental room for future intelligibility tests.

M. L. Groves

D. Information Processing Language

The IBM 709 computer version of IPL-V, the Newell-Shaw-Simon information processing language for computers, has been thoroughly checked out. Some changes have been made to improve compatibility with the 704 version, after consultation with Doctor Newell. As soon as complete, detailed specifications can be agreed upon, further changes will be made in order to achieve complete compatibility of the IPL-V system for the IBM 650, 704 and 709 computers.

A test program has been written in the IPL-V language to exercise all parts of the 709 system, and both this program and the system are working correctly. The test program is being documented, so that it can be made available to other 709 computer installations.

B. F. Green, Jr.
Alice K. Wolf

III. HUMAN INFORMATION PROCESSING

A. Remembering the Present States of a Number of Variables

The fourth experiment on keeping track of a number of variables at once has been completed. As before, the subject is read a series of messages, each of which tells him what state one of the variables has assumed and each of which he records in such a way that he will not see the message after he has recorded it. From time to time he is asked what the present state of one of the variables is.

The present experiment is essentially a repetition of the two that were described in the previous report (Division 5 Quarterly Progress Report for 15 September 1959), but with the subject asked to keep track of only three variables instead of six. The results agree with those from the previous experiments. It now seems possible to state that, under a rather wide variety of conditions, (1) the probability that a message will change the state of the variable to which it refers has a considerable effect on the fraction of the questions answered correctly, and (2) if the fraction correct is adjusted for chance success and if the probability of change is held constant, then the number of states that each variable may assume has no important effect.

D. B. Yntema
Gayle E. Mueser

B. Recall of Visually Presented Words

In an experiment described in the Division 5 Quarterly Progress Report for 15 September 1959, subjects recalled lists of unrelated monosyllables either freely or serially. In the former case, when the subject recalled the words in any order he chose, the total number of words that he could remember increased as an exponential function of the number of times he had seen the list. The total number of words he could recall serially, on the other hand, increased linearly with number of trials. In an attempt to account for the difference between these two kinds of learning curves, the data for free recall have been analyzed by means of three programs written for the IBM 709 computer.

(1) The particular trials on which a given person recalled a given word were determined, and the total frequency with which each such pattern of trials occurred was tabulated. This analysis revealed that the mean number of items recalled for the first time after a given number of trials can be described as a negative binomial distribution. This is true of each individual's distribution as well as that of the group.

(2) The trial on which each word was first recalled by each person was determined, and the mean trial of first recall for each word was estimated across subjects. The frequency distribution of these means was substantially normal.

(3) The number of items recalled for the first time by each person on each trial with a given list was determined and was cumulated across trials, to give frequency distributions of the number of words recalled for the first time on a given trial and of the number of words recalled at least once up to that point. The probability that all of the words in a list had been recalled at least once by the last trial was quite low.

It may be inferred from these results that the negative binomial distribution of items recalled for the first time on each trial is not an artifact of either (a) the unequal difficulty of the items or (b) length of list. This distribution, however, can be predicted from some simple assumptions about the proportion of items that a subject can attend to, or sample, on each presentation of a list and about the number of times that an item must be sampled in order to be recalled. The details of the stochastic model, which also predicts the total number of items recalled on each trial and which subsumes serial learning as a special case, are presently being worked out.

In none of the measures mentioned above was there any difference between the data obtained when the order in which the words were presented was kept constant from trial to trial and those obtained when the words were scrambled before each trial. This suggests that either (1) each word in a list is stored and recalled independently of every other word or (2) the members of a semantic cluster are not necessarily adjacent to each other in a list and do not have to be seen in close temporal succession in order that the cluster be rehearsed.

Nancy C. Waugh

C. Memory for Digits

A rote memory experiment has just been completed using Tufts University students as subjects. The subjects were asked to perform a simple arithmetic operation on decimal digits presented serially in pairs. On some trials they used the same operation throughout the series, and on other trials the operation changed in the middle of the series. They were always asked to recall the pairs of digits in the first part of the series. The effect of change in operation on recall will be determined in the analysis. This experiment is a departure from the classical rote memory experiment in which subjects usually perform no operation upon the input other than to identify it.

B. W. White

D. Visual Psychophysics

Data collection is now complete for the redetermination of the relationship between the intensity of pre-adapting luminance and the time required for the eyes to dark-adapt described in previous reports. Recomputation of the rough data reduction is now being carried out. Individual dark-adaptation contours may be summarized by fitting a Gaussian integral to the plot of per cent approach to maximum sensitivity as a function of the logarithm of time.* The 50 per cent point specifies the duration required to reach a level 3 db below the asymptote and σ is a convenient measure of the rate of adaptation. Data reduction and a report should be completed during the coming reporting period.

R. T. Mitchell
Rhoda Resnick

IV. METHODOLOGY

A. Queuing Studies

Studies of the sampling variability of waiting-time distributions have continued in the past quarter. An earlier study showed that, for the one-server, random input, constant service-time queue, the variability of sample waiting-time distributions, for a fixed sample size,

*W. J. Crozier, Proc. Nat'l Acad. Sci., 26, 334-339 (1940).

increases strongly with system load. During this quarter, the study was repeated using an exponential service-time distribution rather than a fixed service time. Figure 58-1 shows, for samples of 4000 nonzero waits, the average maximum difference between a sample waiting-time distribution and the theoretical waiting-time distribution, as a function of load and service-time distribution.

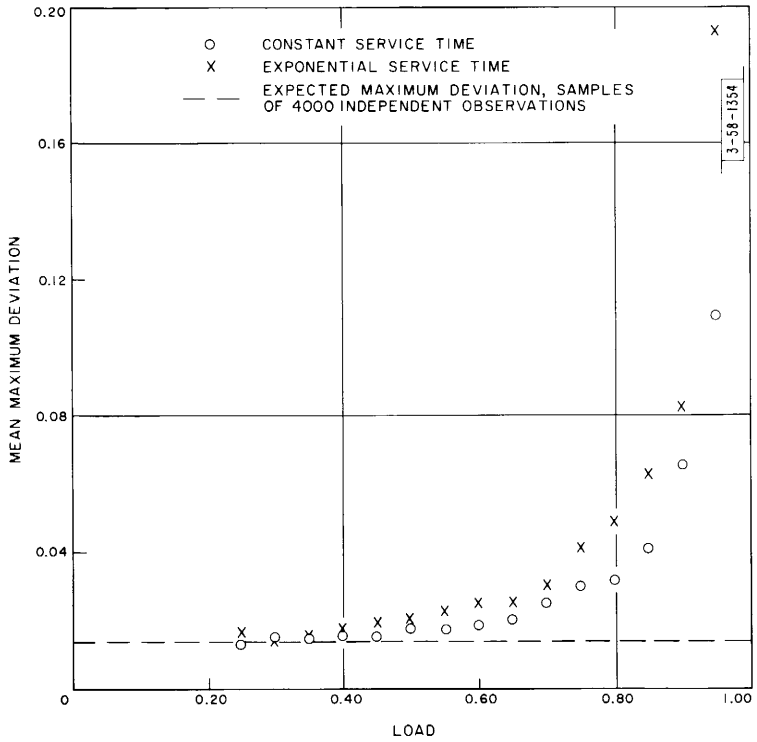

Fig. 58-1. The mean maximum deviation of 50 sample waiting-time distributions from their average (scaled to sample sizes of 4000).

It is clear that, although sampled waits from the exponential service-time queues are more variable over all than those from constant service-time queues, the effect of load is similar in the two systems. These curves should bracket those to be expected with other service-time distributions.

J. E. K. Smith
Laura Klem